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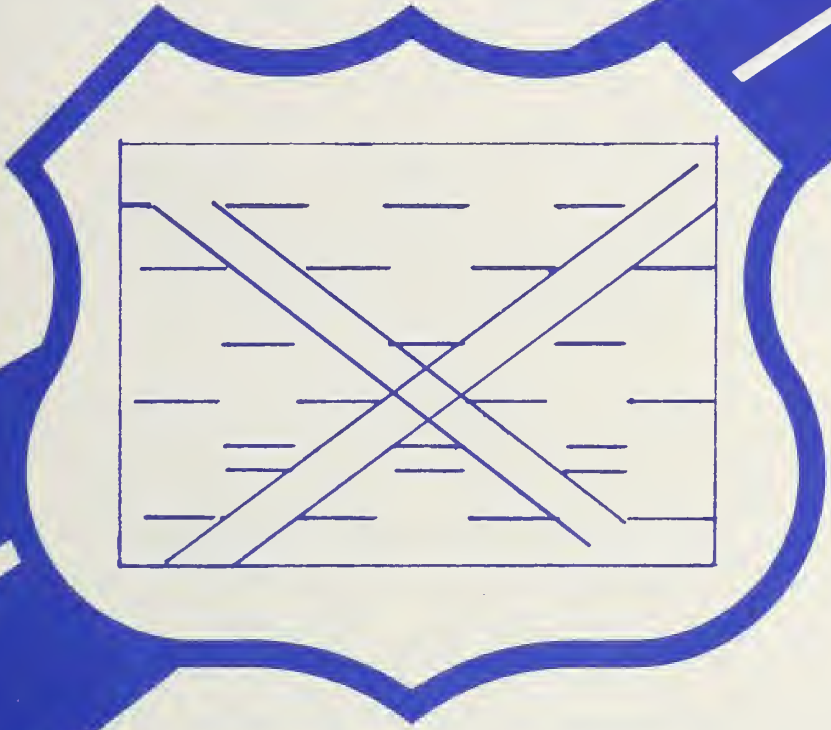
Vol. 2. MAXBAND User's Manual

December 1980
Final Report



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FEDERAL HIGHWAY ADMINISTRATION
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FOREWORD

This report is the user's manual for the MAXBAND program which is designed to optimize signal settings on a signalized arterial or a network of three intersecting arterials, using Little's Maximal Bandwidth Approach. This report is intended for research and traffic operations audiences.

This report is the second volume in a three volume Final Report on the study, "Optimal Signal Settings for Arterial Signal Systems."

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Charles F. Scheffey

Charles F. Scheffey
Director, Office of Research

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16. Abstract

An off-line computer program for setting arterial traffic signals to achieve maximal bandwidth is developed using the mixed-integer linear programming formulation of Little. The computer program, called MAXBAND, is written in FORTRAN IV and portable.

Volume 2, MAXBAND User's Manual, describes in detail the features of the system and their use, including data entry and outputs. Several sample problems, with examples of input and output, are included.

MAXBAND is described in a 3 volume final report

Volume 1	FHWA/RD-80/082	Summary Report
Volume 2	FHWA/RD-80/083	User's Manual
Volume 3	FHWA/RD-80/084	Program Manual

This volume is the User's Manual.

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Chapter 1

INTRODUCTION.

1.1 STARTING OUT.

1.1.1 MAXBAND.

MAXBAND, or Maximal Bandwidth Traffic Signal Setting Optimization Program, is a system which finds traffic signal settings on arteries, or certain networks of three arteries, which result in maximal bandwidths. Problems are formulated as mixed integer programs. The system is based on the traffic signal model developed by J.D.C. Little of the Massachusetts Institute of Technology [1965;1977] and described in Volume 1 of this report. MAXBAND is written in FORTRAN using structured programming techniques.

System inputs include:

1. Network geometry;
2. Signal splits, or traffic volume data on links and link capacities;
3. Range of acceptable cycle lengths;
4. Ranges of acceptable speeds on links;
5. Left turn phasing patterns desired.

Outputs include:

1. Bandwidth durations;
2. Cycle length;
3. Signal splits (if not given in input);
4. Beginning and ending times of splits and bandwidth periods;
5. Left turn and all red phasing patterns;
6. Traversal times and speeds on links.

1.2 HOW TO USE THIS MANUAL.

This manual should instruct new users of MAXBAND and serve as a reference for experienced users. The main sections are:

Chapter 1: Introduction presents the general features and capabilities of MAXBAND. There are also some notes on the system's computer requirements and performance.

Chapter 2: MAXBAND Input Deck and Input Cards describes the input deck and contains the formats of the MAXBAND input cards. It is intended as a reference for both new and experienced users.

Chapter 3: Using MAXBAND explains the specific procedures used to enter problems into MAXBAND. The titles of sections which deal with advanced features are followed by double asterisks (**). The new user may wish to skip these sections on first reading.

Chapter 4: MAXBAND Examples gives four data entry examples.

Chapter 5: MAXBAND Output explains MAXBAND output and contains the output produced by examples 1 and 4 of chapter 3.

The five appendices are intended to be used as references.

Appendix A: MAXBAND Input Warning and Error Messages contains the warning and error messages produced by the INPUT module as it analyzes the input cards. Each message is followed by the name of the card or cards which are most likely to be involved with the production of the message.

Appendix B: MAXBAND Output Error Messages lists the messages produced by the OUTPUT module when the MPCODE module has not successfully completed.

Appendix C: MAXBAND Input Forms contains forms which can be used for gathering data to be given to MAXBAND. These are the forms which are used in Chapter 4.

Appendix D: MAXBAND's Internal Split Model and the Split Derivation Process explains the split model used in MAXBAND, and the process by which MAXBAND obtains the splits used in the problem formulation.

Appendix E: Sample Outputs contains the Maxband output for examples 2 and 3 of Chapter 4.

1.3 MAXBAND'S CAPABILITIES.

1.3.1 Types of problems handled.

MAXBAND can determine optimal signal settings for arteries or loops -- networks of three arteries described below.

1.3.1.1 Arteries.

An artery is a series of 2 to 20 signalized intersections along a street, together with connecting roadways. Intersections may be 4-way or t-shaped, or there may be no cross street at all. MAXBAND analyzes each intersection as though there are at most four phases: a main street phase; a cross street phase; and up to two 'all red' phases during which both the main and cross streets have a red light. The main and cross street phases are in turn divided into green and left phases in each direction.

The two directions of an artery are referred to as outbound and inbound.

An artery may be one-way for all or part of its length.

1.3.1.2 Loops.

In MAXBAND, a network of three arteries in which each artery intersects the other two at distinct intersections is called a loop. Figure 1 shows the typical loop shape.

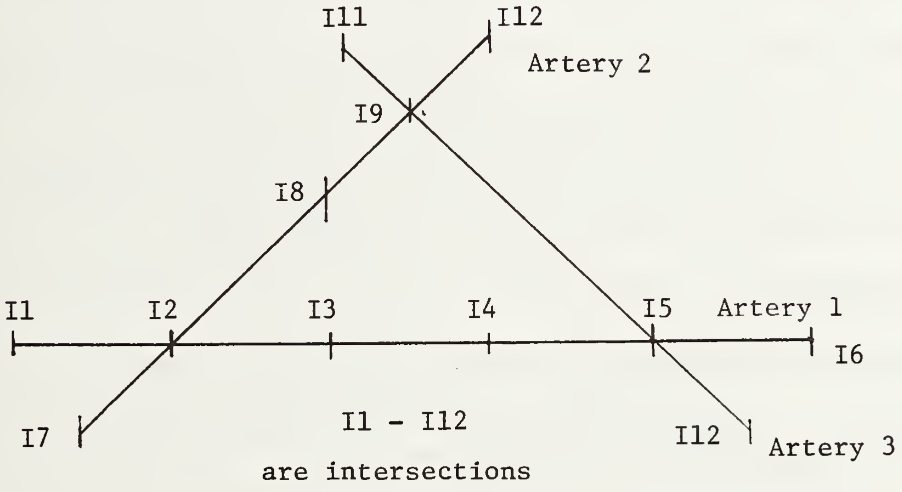


Figure 1: A loop.

The total number of intersections in the loop must be in the range 3 - 17, with each artery having 2 - 16 intersections. In general, each of the three arteries is analyzed in the same way as the one artery of the single artery case.

1.3.2 Inputs.

1.3.2.1 Arteries.

MAXBAND requires the following information in single artery problems:

1. Number of intersections;
2. Units (English or metric);
3. Map direction from which intersections are entered;
4. Cycle time limits;
5. Artery-wide design speeds and tolerances on links, and allowed changes in speed between links;
6. Either main street splits, or volume and capacity information on intersection approaches from which main street splits will be calculated;
7. Left turn phasing patterns to be considered, if there are left turn splits;
8. Link lengths.

The user may allow some of this information to default.

The following informtion is optional in single artery problems:

1. Design speeds and tolerances for specific links;
2. Minimum split durations;
3. Bandwidth period advance times to allow for queues;
4. Values to control the relative importance of the outbound and inbound bandwidths in the solution;
5. The artery name and cross street names and node numbers at the intersections.

1.3.2.2 Loops.

Loop input consists of general information about the loop as a whole, plus specific information about each of the three arteries. The input for each artery is the same as in the previous section, except that cycle time limits are excluded, being given for the entire loop instead of each artery.

The follow information is required in the loop case:

1. Number of intersections;
2. Cycle time limits;
3. Loop geometry, i.e., where the three arteries intersect with each other;
4. Single artery information (except for cycle time limits) for each of the three arteries.

In addition, the following information is optional:

1. Values to control the relative importance in the solution of the three outbound bandwidths;
2. Name of the loop.

1.3.3 Outputs.

1.3.3.1 Arteries.

MAXBAND produces the following information about the optimal solution of the artery problem:

1. Duration of the outbound and inbound bandwidths;
2. Artery-wide cycle time;
3. Beginning and ending times of green, red, left and bandwidth periods;
4. The duration of the green, red and left periods if these were computed from volume and capacity information;
5. Left turn phasing pattern selected (if there are left turn splits);
6. Progression traversal times and speeds on links.

1.3.3.2 Loops.

Maxband produces the following information about the optimal solution for loop problems:

1. Loop-wide Cycle time;

2. Beginning, and and duration of any all red periods at artery meetings.

3. The single artery output information for each of the three arteries.

In addition, the signal settings and phase durations from point 3 at artery meetings are repeated at the end of the output.

1.4 STRUCTURE OF THE SYSTEM.

Figure 2 shows the overall structure of the MAXBAND system. The sytem consists of five modules: an overall control module (MAXBAND); and four modules which handle specific subtasks (INPUT, MATGEN, MPCODE and OUTPUT). The latter four modules execute sequentially.

1.4.1 The MAXBAND Module.

The MAXBAND module contains the main program and several subroutines. It provides overall control of the system.

1.4.2 The INPUT module.

The INPUT module reads the input cards on FORTRAN file 4, and places their card images in a temporary disk file on FORTRAN file 5. It then reads the card images from file 5, checks them for errors and converts the information they contain into the internal form used by MAXBAND. This conversion includes the calculation of splits from volume and capacity information, when this is to be done, and the modification of splits to satisfy minimum split times.

The INPUT module produces the first portion of the MAXBAND output on FORTRAN file 6. It first echoes the input cards. Interspersed among and following the echoes are any warning and error messages produced when errors are found in the input cards. If no serious errors are detected, the module then prints an input data summary. This contains the final version of the input information which will be passed to the Matrix Generator (MATGEN) module.

The user can specify that MAXBAND halt after the INPUT module has executed. The system will produce only the input card echoes and the input data summary.

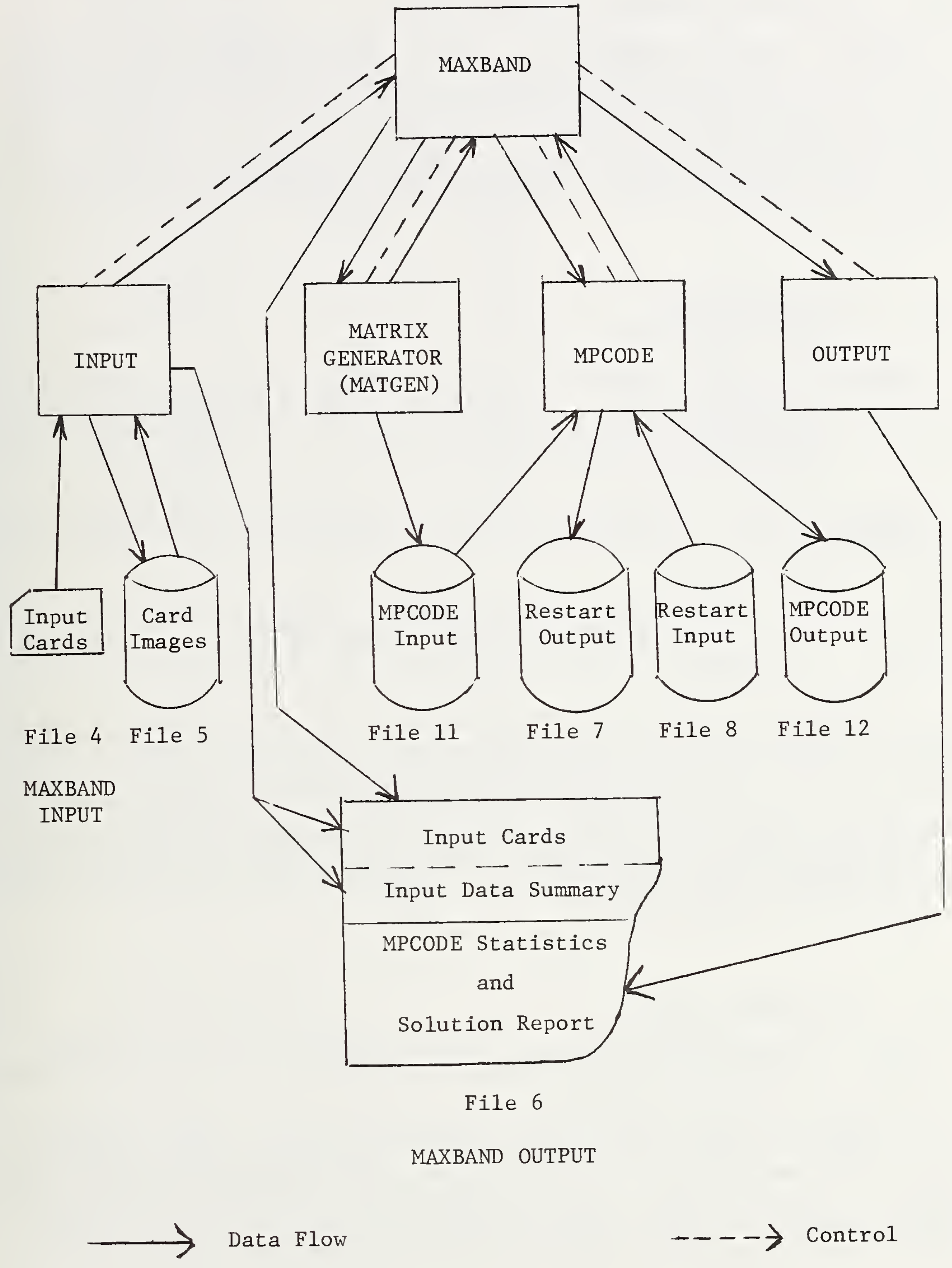


Figure 2: Structure of MAXBAND System.

1.4.3 The Matrix Generator (MATGEN) Module.

MAXBAND formulates problems as mixed integer mathematical programs. These are solved by the MPCODE module, which contains the MPCODE Mathematical Programming System. After the input data has been translated to the internal form by the INPUT module, the Matrix Generator (MATGEN) module builds this information into a mixed integer formulation, which is used as input to the MPCODE module. The MATGEN module places this formulation on FORTRAN file 11.

1.4.4 The MPCODE Module.

MAXBAND uses the MPCODE mathematical programming system, written by A. Land and S. Powell [1973], to solve the problem formulations produced by the MATGEN module. The mixed integer portions of the MPCODE system have been placed in the MPCODE module.

The module reads the problem formulation produced by the MATGEN module on FORTRAN file 11, solves the problem, and passes the results back to the MAXBAND control module.

The output capabilities of the original MPCODE system have been retained. The MPCODE module writes the MPCODE output described by Land and Powell on FORTRAN file 12. This file may be dummied if not required.

The MPCODE module also incorporates the restart capabilities of the original MPCODE system. If the upper limit on the total number of iterations is about to be exceeded, the module will stop trying to solve the problem and will write a restart file to FORTRAN file 7. The restart file contains the state of the module just before the file is written. If the user later chooses to restart the problem, the MPCODE module will read the latest restart file on FORTRAN file 8. This prevents the system from have to repeat work already done.

1.4.5 The OUTPUT Module.

After the MPCODE module has completed, MAXBAND calls the OUTPUT module to report any solution found.

The OUTPUT module first reports whether the MPCODE module has found a solution and whether any error conditions were encountered. It then gives statistics describing the operation of the MPCODE system. Finally, if MPCODE was able to find a problem solution, the OUTPUT module prints the signal settings and other values given by this solution.

1.5 OPERATING SYSTEM NOTES.

1.5.1 FORTRAN Files.

Maxband uses the FORTRAN logical files shown in figure 3.

DDNAME	RECFM	LRECL	USE
FN04F001	FB	80	card input
FN05F001	FB	80	card images (temporary disk file)
FN06F001	FB	133	output
FN07F001	FB	80	restart output
FN08F001	FB	80	restart input
FN11F001	FB	80	MPCODE input
FN12F001	FB	133	MPCODE output

Figure 3: MAXBAND FORTRAN Files.

File 8 is normally dummied, except when restarting. File 12 may also be dummied if the user does not need the MPCODE system output.

At MIT, MAXBAND was run on an IBM 370/168 using the Conversational Monitor System (CMS) operating system. The CMS exec shown in figure 4 was used. The modules were broken into smaller pieces to facilitate loading.

1.5.2 Core Requirements.

Figure 5 gives the minimum amounts of core required by each of the five modules.

MAXBAND, INPUT, MATGEN and OUTPUT were compiled using the FORTRAN IV G compiler; MPCODE was compiled by the FORTRAN H Extended compiler, using the optimize(2) option.

This figure does not include any core which may be required by the operating system.

Since the INPUT, MATGEN, MPCODE and OUTPUT modules execute sequentially, they may overlay each other. The MAXBAND module must be in memory at all times.

```
*
*    SOLVE PROBLEM &1 BY CALLING MAXBAND
*
     FILE 4 DISK &1 DATA (RECFM FB LRECL 80 BLOCK 800
     FILE 5 DISK &1 TEMP (RECFM FB LRECL 80 BLOCK 800
     FILE 6 DISK &1 MAXBAND (RECFM FB LRECL 133 BLOCK 798
     FILE 7 DISK &1 RESTART (RECFM FB LRECL 80 BLOCK 800
     FILE 8 DUMMY
     FILE 11 DISK &1 MATGEN (RECFM FB LRECL 80 BLOCK 800
     FILE 12 DISK &1 LP (RECFM FB LRECL 133 BLOCK 798
*
     &A = MAXBAND
     &B = INPUT1
     &C = INPUT2
     &D = INPUT3
     &E = MATGEN
     &F = MATGENA
     &G = MATGENL
     &H = MPCODE
     &I = OUTPUT1
     &J = OUTPUT2
     &K = OUTPUT3
*
     LOAD &A &B &C &D &E &F &G &H &I &J &K (START
*
```

Figure 4: Running MAXBAND under IBM 370/168 CMS.

MODULE	MINIMUM CORE (K)
MAXBAND	8
INPUT	114
MATGEN	84
MPCODE	245
OUTPUT	89
total	540

Figure 5: Minimum core required by the modules.

Figure 6 shows the subroutines which compose each module.

MODULE	SUBROUTINES
MAXBAND	MAXBAND to MAXEND
INPUT	INPUT to ISTUNT
MATGEN	MATGEN to LEOF
MPCODE	MPCODE to RESTRT
OUTPUT	OUTPUT to JNTLSC

Figure 6: The subroutines composing each module.

MAXBAND was tested at the Federal Highway Administration on an IBM 360 model 65 computer, using overlays. The overlay control cards used are shown in the MAXBAND Programmer's Manual. The overlay segments required the following amounts of core:

SEGMENT CONTENTS (SUBROUTINES)	REQUIRED CORE (K)
Main program, unlabeled common and system routines	201
MAXHD, MAXEND	1
INPUT	18
INPUT - CMING	38
COMPTE - CKMAX	25
SUMARY - ISTUNT	20
MATGEN	2
MATGNA - EOF	27
MATGNL - LEOF	38
MPCODE - PLP, labeled common	69
OUTPUT, GDOUT	19
BADOUT - AGAMS	10
SETVAR - SETLNK	19
REPORT -JNTLSC	33
maximum core required at one time	273

Figure 7: The core required by the overlay segments.

1.6 SYSTEM PERFORMANCE.

Figure 8 gives performance statistics for a series of problems solved by MAXBAND. These were run at MIT on an IBM 370/168 computer using the Conversational Monitor System (CMS) operating system. The figure includes details of the problem formulation given to the MPCODE system.

MAXBAND Problem Formulation

Artery Problems:	# Signals	# Vars.	# Cons.	# Int.Vars Total	Free	# Iter.	# Sols.	CPU time (sec)	Cost ($)
1. Broadway, Cambridge	5	25	45	4	4	36	1	2.17	0.73
2. Voorhees Scenario 1 - Test network 4	6	30	56	5	5	668	2	5.81	1.07
3. Short version of Waltham artery - Test network 2	6	33	56	8	8	197	3	3.23	0.76
4. Voorhees Scenario 2 - Test network 5	6	36	56	11	11	957	6	7.01	1.23
5. Voorhees Scenario 2 - computed splits	6	36	56	11	11	1457	5	9.74	1.52
6. Modified Voorhees Scenario 2 - Computed splits	6	42	56	17	17	607	7	6.26	1.35
7. Voorhees Scenario 1 - Computed splits	6	42	56	17	17	2089	6	14.08	2.03
8. Modified Waltham artery - Test network 2	11	60	116	15	10	1296	4	17.16	2.44
9. Modified Waltham artery - Test network 2	11	60	116	15	10	2450	6	31.57	4.11
10. Waltham artery - Test network 2	11	60	111	15	15	3781	7	44.79	5.69
11. Wisconsin Ave., Wash. DC	17	88	177	19	19	8700	12	~210	~25.00

Figure 8: MAXBAND performance statistics.

MAXBAND Problem Formulation

Loop Problems:	# Signals	# Vars.	# Cons.	# Int.Vars Total	Free	# Iter.	# Sols.	CPU time (sec)	Cost ($)
1. Modified Attleboro loop -Test network 3	4	36	44	5	5	286	3	3.69	0.84
2. Attleboro loop - Test network 3	4	37	44	5	5	432	4	4.44	0.92
3. FHWA Test Network - Test network 1	15	93	168	19	16	32885	15	628.81	74.87

Notes: Vars. = Variables
Cons. = Constraints
Int. = Integer
Iter. = Iterations
Sols. = Solutions

Figure 8: Continued

Chapter 2

MAXBAND INPUT DECK AND INPUT CARDS.

This chapter discusses the MAXBAND input deck, and the individual MAXBAND cards, their data items, and the associated warning and error messages. It is intended as a reference for both new and experienced users. A general introduction to using the system, including discussions of the cards and the information they contain, is found in chapter 3. contain, is found in chapter 3.

2.1 THE MAXBAND INPUT DECK.

The general formats for artery and loop input decks is shown in figures 9 and 10. In figure 11 they have been divided into six functional groups.

In the artery case, the deck begins with the START card. Optionally, this may be followed by the MPCODE card. Next are the cards which establish the problem as an artery problem and give general artery information (group 3). After these are sets of cards giving information about a specific signal and its approaches (group 5). The deck ends with the END card.

The loop deck also begins with the START card, followed optionally by the MPCODE card. Next come cards which indicate that the problem deals with a loop and give general information about the loop (group 4). Following these are cards introducing the first artery (group 3), which are followed by sets of cards with information about each intersection in the artery (group 5), just as in the single artery case. The group 3 and group 5 cards are then repeated for the other two arteries. Note that the three artery sections begin with SETUP1, SETUP2 and SETUP3 cards, respectively, and not SETUP cards, as in the single artery case. The deck is completed by an END card.

The cards must be entered in exactly the order shown in figures 9 and 10, with the exception that, at each intersection, although the MAP card ust be the first group 5 card entered, the remaining group 5 cards for e intersection may be entered in any order, as long as they are all ered before the next MAP, SETUP2, SETUP3 or END card.

```
GROUP                                     CARD NAME

 1                                         START *

 2                                        [MPCODE]

 3                                         SETUP
                                           ARTERY
                                           ART2

 5                                     /   MAP †
                                      |  { SPECIFY   }      { VOLUME   }
                       repeat for     | { [VOLUME]    } or {           }
                          each        |  {[CAPACITY] }      { CAPACITY }
                      intersection    { [MINGREEN]
                     (2 - 20 times)   | [LEFTPAT]
                                      |  LENGTH
                                      | [SPEED]
                                       \ [QUEUE]

 1                                         END *
```

[ ] - optional
*   - may be omitted, but this causes a warning message

†   - the MAP card must be the first signal and approach card (group 5) to be entered for each intersection

NOTES:

1. Except for the MAP card, the signal and approach cards (group 5) for an intersection may be entered in any order.
2. When certain values are entered on the ART2 card, a VOLUME card is required for all intersections included in the analysis.
3. COMMENT cards may be placed anywhere in the deck. However, they will not be printed in the output if they are placed after the END card.

Figure 9: The general artery deck.

Group		Card Name	
1		START *	
2		[MPCODE]	
4		SETUPL	
		LOOP1	
		[LOOP2]	
3	artery 1	SETUP1	
		ARTERY	
		ART2	
5		MAP †	repeat for each intersection in artery 1 (2 - 16 times) Ⓑ
		Ⓐ	
3	artery 2	SETUP2	
		ARTERY	
		ART2	
5		MAP †	repeat for each intersection in artery 2 (2 - 16 times) Ⓑ
		Ⓐ	
3	artery 3	SETUP3	
		ARTERY	
		ART2	
5		MAP †	repeat for each intersection in artery 3 (2 - 16 times) Ⓑ
		Ⓐ	
1		END *	

[ ] - optional
* - may be omitted, but this causes a warning message
† - the MAP card must be the first signal and approach card (group 5) to be intered for each intersection.
Ⓐ - the signal and approach cards (group 5) are used here as in a single artery deck.
Ⓑ - the total number of MAP cards in a loop deck may not exceed 20.

Notes 1, 2 and 3 from figure 9 apply here also.

Figure 10: The general loop deck.

1.	Starting and ending the job, and controlling output.	START END
2.	Controlling operation of the maximization routine (MPCODE).	MPCODE
3.	Starting an artery section and giving general artery information.	SETUP SETUP1 SETUP2 SETUP3 ARTERY ART2
4.	Starting a loop problem and giving general loop information.	SETUPL LOOP1 LOOP2
5.	Giving information about a specific signal and its approaches.	MAP SPECIFY VOLUME CAPACITY MINGREEN LEFTPAT LENGTH SPEED QUEUE
6.	Other cards.	COMM

Figure 11: The six types of MAXBAND input cards.

2.2 CARD FORMAT.

All MAXBAND cards use a modified form of the format shown in figure 12.

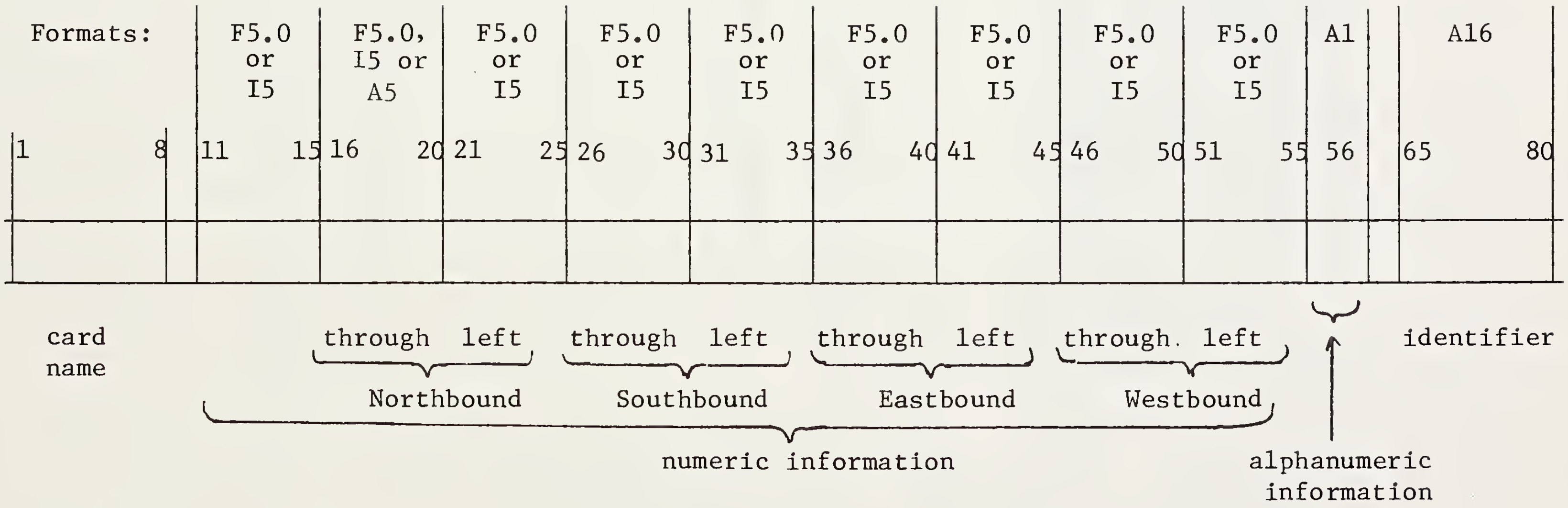
Columns 1-8 are reserved for the card name.

Columns 11-15, 16-20, 21-25, 26-30, 31-35, 36-40, 41-45, 46-50 and 51-55 contain numeric information. Since these fields are read using the Fortran F or I formats, numbers entered in them must be right-justified. Note, however, that the node number field of the MAP card (columns 16-20) is read in A5 format, and so does not have to be right-justified. In some cards, only the right-most 1 or 2 characters of these fields might be read. For the signal and link specific (group 5) cards other than MAP, columns 16-25, 26-35, 36-45 and 46-55 contain information for the northbound, southbound, eastbound and westbound directions, respectively. On the SPECIFY, VOLUME, CAPACITY and MINGREEN cards, the first field in each direction is for through information; the second field is for left information.

Column 56 is used on the SETUP cards to indicate the direction from which signals are entered.

Columns 65-80 give identification information. They are read in A16 format.

In the following discussions, the cards are arranged into the six groups of figure 11.



Note: Most numeric fields are read twice. First they are read in A5 format to see if they are blank. They are then read in the appropriate numeric format.

Figure 12: The general MAXBAND input card format.

2.3 INPUT FIELD DESCRIPTIONS AND DEFAULTS.

For each field of a card, the 'Input fields' section dealing with that card gives

1. The column numbers of the field;
2. The format in which the field is read;
3. A description of the field's contents; and
4. The number of the section of chapter 3 or chapter 5 in which the field is described.

The description in point 3 includes

1. A short description of the field;
2. The values which can be placed in the field (Values:); and
3. The values the field assumes if it defaults (Defaults:).

Note that, when there is a default capability, it is usually triggered by leaving the field blank. Hence the user should be careful not to leave fields blank unless the default is desired or there is no default capability for the field.

If a default is caused by some value other than the blank (hex 40), this is noted under the 'Defaults:' heading of the 'Input fields' section.

2.4 CARDS WHICH START AND END A JOB AND CONTROL OUTPUT (GROUP 1).

2.4.1 The START card.

The START card is used to begin a deck and to control the amount of output. It is the first card in the input deck. The START card may be omitted from the deck, but this will cause a warning message to be printed. If the card is omitted, the message level and warning level default to zero.

2.4.1.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-5	-	Word 'START'	-

11-15	I5	Message level. Values: 0 - Output to include Input Cards, Input Data Summary, MPCODE Statistics, and Solution Report 1 - Output to include Input Data Summary, MPCODE Statistics and Solution Report 2 - Output to include MPCODE Statistics and Solution Report 3 - Output to include Input Cards and Input Data Summary. The program will not proceed beyond the input analysis stage in this case. Default: 0	5.2
16-20	I5	Warning level. Values: 0 - warning messages are printed 1 - Warning messages are not printed Default: 0	5.2

Notes:

1. If the START card is omitted, the message level and the warning level default to zero.

2.4.1.2 Warning and error messages.

```
****  WARNING  ****  NO START CARD.  DEFAULT VALUE FOR MESSAGE  LEVEL AND
                     WARNING LEVEL ASSUMED.

****  WARNING  ****  BAD VALUE GIVEN FOR MESSAGE LEVEL. ZERO ASSUMED.

****  WARNING  ****  BAD VALUE GIVEN FOR WARNING LEVEL. ZERO ASSUMED.
```

2.4.2 The END card

The END card is used to indicate the end of the input information. Hence, it is placed after all the other cards which contain information. Any cards placed after the END card, including a COMM card, will be ignored. The END card may be omitted, but this will cause a warning message to be produced.

2.4.2.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-3	-	Word 'END'	-

Notes:

1. Except for its name, the END card is entirely blank.

2.4.2.2 Warning and error messages.

```
****  WARNING  ****  END OF FILE HAS BEEN REACHED WITHOUT AN END CARD.

****  ERROR  ****  END OF FILE HAS BEEN REACHED PREMATURELY.
```

2.5 CARD TO CONTROL THE OPERATION OF MPCODE (GROUP 2).

2.5.1 The MPCODE card.

The MPCODE card contains parameters which control the operation of the maximization routine used by MAXBAND, MPCODE. Except when restarting, the card is optional. If present, it must immediately follow the START card and precede the SETUP or SETUPL card.

2.5.1.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-6	-	Word 'MPCODE'	-
11-20	I10	Maximum number of maximization iterations allowed (MAXRBB). Value: must be $\geq$ 0 Default: 10000	3.4

21-25	I5	Maximum number of maximization reinversions allowed (MAXIBB). Value: must be $\geq$ 0 Default: 100	3.4
26-30	I5	Maximum number of iterations allowed to a single linear program (MAXITR). Value: must be $\geq$ 0 Default: 1000	3.4
31-35	I5	Maximum number of reinversion allowed to a single linear program (MAXINV). Values: must be $\geq$ 0 Default: 100	3.4
36-40	I5	Restart indicator. Values: 0 - Job is not a restart 1 - Job is a restart Default: 0	3.10

Notes:

1. If the MPCODE card is omitted, MAXRBB, MAXIBB, MAXITR, MAXINV and the restart indicator assume their default values.

2.5.1.2 Warning and error messages.

**** ERROR **** AN ILLEGAL VALUE FOUND ON MPCODE CARD.

2.6 CARDS WHICH INTRODUCE AN ARTERY (GROUP 3).

2.6.1 The SETUP, SETUP1, SETUP2 and SETUP3 cards.

Each of the SETUP, SETUP1, SETUP2 and SETUP3 cards is used as the first card of a series describing an artery, and contains general information about the artery. The SETUP card is used in the single artery problem, and must immediately follow the START card, or MPCODE card if present. The SETUP1, SETUP2 and SETUP3 are used in the loop problem to begin the sections dealing with each of the three arteries. The SETUP1 card must immediately follow the LOOP1 card, or LOOP2 card if present. The SETUP2 card must be the first card after the last card describing an individual intersection in artery 1, and the SETUP3 card must be the first card after the last card describing an individual intersection of artery 2. The

SETUP card is mandatory in the artery problem, and the SETUP1, SETUP2 and SETUP3 cards are mandatory in the loop problem. Except for their names, all four cards have the same format.

2.6.1.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-5 or 1-6	-	Word 'SETUP', 'SETUP1', 'SETUP2' or 'SETUP3'	-
19-20	I2	Number of intersections in artery. Range: 2 - 20 for SETUP card 2 - 16 for SETUP1, SETUP2 or SETUP3 card Default: None. A value must be entered.	3.5.1
40	I1	Metric option. Values: 0 - English units used 1 - metric units used Default: 0	3.5.2
56	A1	Direction of entry (inbound direction). Range: N,S,E or W Default: None. A value must be entered.	3.5.3
65-80	A16	Name of arterial	3.5.4

Notes:

1. The direction of entry determines which fields of the signal and approach specific (group 5) cards will be read for data.

2.6.1.2 Warning and error messages.

```
**** WARNING **** NUMBER OF INTERSECTIONS ENTERED DOES NOT AGREE WITH
                  NUMBER ON SETUP CARD.
```

```
**** WARNING **** LAST INTERSECTION  NUMBER IS  GREATER THAN  NUMBER ON
                  SETUP CARD.

**** ERROR **** NO SETUP OR SETUPL CARD FOUND.

**** ERROR **** NO SETUPi CARD.

**** ERROR **** ILLEGAL NUMBER OF INTERSECTIONS IN ARTERY.

**** ERROR **** BAD ENTRY DIRECTION.
```

2.6.2 The ARTERY card.

The ARTERY card contains general information about an artery. It is mandatory. In the single artery problem, it must be entered immediately after the SETUP card. In the loop problem, an ARTERY card card must be entered immediately after each of the SETUP1, SETUP2 and SETUP3 cards.

2.6.2.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-6	-	Word 'ARTERY'	-
11-15	F5.0	Lower limit on artery cycle time. Range: Must be > 0 and $\le$ the value in columns 16-20 Default: In artery problem, none -- a value must be entered. In loop problem, this field is ignored.	3.5.6
16-20	F5.0	Upper limit on artery cycle time. Range: Must be > 0 and $\ge$ the value in columns 11-15 Default: In artery problem, none -- a value must be present. In loop problem, this field is ignored.	3.5.6

41-45	I5	First intersection of those read in to be used in the analysis. Range: 1 - 19 in artery deck 1 - 15 in loop deck. Also see below. Default: 1	3.5.7
46-50	I5	Last intersection of those read in to be used in the analysis. Range: 2 - 20 in artery deck 2 - 16 in loop deck. Also see below. Default: Value in columns 19-20 of SETUP, SETUP1, SETUP2 or SETUP3 card.	3.5.7

Notes:

1. The value in columns 41-45 must be less than the number of intersections read in, and less than the value in columns 46-50.

2. The value in columns 46-50 must be greater than the value in columns 41-45.

3. Important: In MAXBAND, minimum green times are entered in fractions of a cycle. Care must be taken in selecting a lower cycle limit that it is great enough to provide the minimum green times desired in seconds. If splits at an intersection are computed from volume and capacity information, but no MINGREEN card is entered, MAXBAND will use default minimum green times of 0.05 cycles.

2.6.2.2 Warning and error messages.

```
****  WARNING  ****  LAST INTERSECTION  NUMBER IS  GREATER THAN  NUMBER ON
                     SETUP CARD.

****  WARNING  ****  LAST  INTERSECTION  SPECIFIED FOR  ARTERY  X  EXCEEDS
                     ACTUAL NUMBER ENTERED.  ARTERY WILL BE ANALYZED UP TO
                     LAST INTERSECTION ACTUALLY ENTERED.

****  ERROR  ****  NO ARTERY CARD.

****  ERROR  ****  BAD CYCLE TIME LIMIT.
```

**** ERROR **** LOWER CYCLE TIME LIMIT IS GREATER THAN UPPER CYCLE TIME LIMIT.

**** ERROR **** ILLEGAL VALUE FOR FIRST OR LAST INTERSECTION.

**** ERROR **** FIRST INTERSECTION HAS A NUMBER HIGHER OR EQUAL TO THAT OF LAST.

**** ERROR **** THE FIRST AND LAST INTERSECTIONS IN ARTERY X TO BE USED DO NOT SPECIFY AT LEAST TWO INTERSECTIONS.

2.6.3 The ART2 card.

The ART2 card contains bandwidth and speed information for an artery. It is mandatory, and must appear immediately after the ARTERY card for the artery.

2.6.3.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-4	-	Word 'ART2'.	-
11-15	F5.0	Target bandwidth ratio, inbound to outbound direction (k). Range: Must be $\geq$ 0. If a -1 is placed in this field, k will computed from volume information. Default: 1	3.5.9
16-20	F5.0	Weight of outbound bandwidth in objective function (c(1)). Range: Must be $\geq$ 0. If a -1 is entered in this field, c(1) will be computed from volume information. Default: 1.	3.5.9

21-25	F5.0	Weight of inbound bandwidth in objective function (c(2)). Range: Must be ≥ 0. If a -1 is entered in this field, c(2) will be computed from bolume information. Default: 1.	3.5.9
26-30	F5.0	Artery outbound design speed. Range: Must be > 0. Default: Artery inbound design speed (columns 41-45).	3.5.10
31-25	F5.0	Artery outbound design speed tolerance. Range: Must be ≥ 0 and $\leq$ artery outbound design speed (columns 26-30). Default: 0.1 x artery outbound design speed (columns 26-30).	3.5.10
36-40	F5.0	Change in speed allowed between consecutive outbound links. Range: Must be ≥ 0 and $<$ artery outbound design speed (columns 26-30) and artery outbound design speed tolerance (columns 31-35). Default: artery outbound design speed tolerance (columns 31-35).	3.5.10
41-45	F5.0	Artery inbound design speed. Range: Must be > 0. Default: Artery outbound design speed (columns 26-30).	3.5.10
46-50	F5.0	Artery inbound design speed tolerance. Range: Must be ≥ 0 and $\leq$ artery inbound design speed (columns 41-45). Default: 0.1 x artery inbound design speed tolerance (columns 41-45).	3.5.10

51-55	F5.0	Change in speed allowed between consecutive inbound links. Range: Must be ≥ 0 and < artery inbound design speed (columns 41-45) and artery inbound design speed tolerance (columns 46-50). Default: artery inbound design speed tolerance (columns 46-50).	3.5.10

Notes:

1. If k, c(1) or c(2) is to be computed from volume information (i.e., a -1 has been entered in columns 11-15, 16-20 or 21-25, respectively), a VOLUME card must be included for each of the intersections being analyzed in the artery (these intersections are determined by the values in columns 41-45 and 46-50 of the ARTERY card).

2. The values for the artery design speeds, artery design speed tolerances, and changes in speed allowed between consecutive links are used for all links in the artery. The design speeds and tolerances may be overridden on a particular link by the SPEED card.

3. At least one of the outbound or inbound design speeds must be entered (i.e., at least one of columns 26-30 and 41-45 must not be blank).

4. In each direction, the three speed values entered on the ART2 card must also satisfy the following constraints:

   a) The design speed tolerance cannot be larger than the design speed along any link.

   b) The change in speed allowed between links cannot be larger than smallest value of

      design speed + design speed tolerance

      for all the links in the direction on the artery.

   c) The range

      (design speed - design speed tolerance - allowed change,
      design speed + design speed tolerance + allowed change)

      on one link must overlap the range

      (design speed - design speed tolerance,
      design speed + design speed tolerance)

on the next link.

2.6.3.2 Warning and error messages.

**** WARNING **** THERE IS NO VOLUME ON ARTERY X. IF K, C(1), OR C(2) ARE TO BE COMPUTED FROM VOLUME DATA, THEY HAVE BEEN SET TO ONE.

Note: This condition should never occur if MAXBAND is executing properly.

**** ERROR **** NO ART2 CARD.

**** ERROR **** NO SPEED INFORMATION ON ART2 CARD.

Note: This means that both columns 26-30 and 41-45 are blank.

**** ERROR **** ILLEGAL SPEED, TOLERANCE OR CHANGE VALUE.

**** ERROR **** IT HAS BEEN REQUESTED THAT K, C(1), OR C(2) BE COMPUTED FROM VOLUME INFORMATION FOR ARTERY X, BUT VOLUME INFORMATION HAS NOT BEEN SUPPLIED FOR EVERY INTERSECTION.

Note: This condition should never occur if MAXBAND is executing properly.

**** ERROR **** A TOLERANCE IS GREATER THAN DESIGN SPEED ALONG SOME LINK OF ARTERY X.

**** ERROR **** A CHANGE VALUE EXCEEDS OR EQUALS THE MINIMUM OF UPPER SPEED LIMITS OF LINKS ALONG ARTERY X.

**** ERROR **** A CHANGE OF SPEED VALUE IS NOT LARGE ENOUGH ON ARTERY X.

2.7 CARDS WHICH INTRODUCE A LOOP (GROUP 4).

2.7.1 The SETUPL card.

The SETUPL card indicates that the problem is a loop and begins the loop information section. It is mandatory, and must be the first card after the START card, or MPCODE card if present.

2.7.1.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-6	-	Word 'SETUPL'	-
19-20	I2	Number of intersections in loop. Range: 3 - 17 Default: None. A value must be entered.	3.6.1
65-80	A16	Name of loop.	3.6.2

2.7.1.2 Warning and error messages.

```
**** WARNING **** NUMBER OF INTERSECTIONS ENTERED ON SETUPL CARD DOES
                  NOT AGREE WITH NUMBER READ IN.

**** ERROR **** NO SETUP OR SETUPL CARD FOUND.

**** ERROR **** ILLEGAL NUMBER OF INTERSECTIONS IN LOOP.
```

2.7.2 The LOOP1 Card.

The LOOP1 card contains cycle time limits for the loop and information about the loop geometry. It is mandatory, and must appear after the SETUPL card.

2.7.2.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-5	-	Word 'LOOP1'	-
11-15	F5.0	Lower cycle time limit. Range: Must be > 0 and ≤ upper cycle time limit (columns 16-20). Default: None. A value must be entered.	3.6.3

16-20	F5.0	Upper cycle time limit. Range: Must be > 0 and ≥ lower cycle time limit (columns 11-15). Default: None. A value must be entered.	3.6.3
		The intersection of arteries 1 and 2:	
26-30	I5	Intersection number in artery 1. See below.	3.6.4
31-35	I5	Intersection number in artery 2. See below.	3.6.4
		The intersection of arteries 1 and 3:	
36-40	I5	Intersection number in artery 1. See below.	3.6.4
41-45	I5	Intersection number in artery 3. See below.	3.6.4
		The intersection of arteries 2 and 3:	
46-50	I5	Intersection number in artery 2. See below.	3.6.4
51-55	I5	Intersection number in artery 3. See below.	3.6.4

Notes:

1. The cycle time limits on the LOOP1 card apply for all three arteries in a loop. Any values entered in columns 11-15 and 16-20 of the three ARTERY cards for the lower and upper limits are ignored.

2. Important: In MAXBAND, minimum green times are entered in fractions of a cycle. Care must be taken in selecting a lower cycle limit that it is great enough to provide the minimum green times desired in seconds. If splits at an intersection are computed from volume and capacity information, but no MINGREEN card is entered, MAXBAND will use default minimum green times of 0.05 cycles.

3. The signal numbers entered in columns 26-55 must be in the range 1 - 16. These numbers refer to MAXBAND's internal 'order of entry' numbers, and so must be in the range 1 to n, where n is the number of signals entered for a particular artery. There are no defaults for the six numbers. Values must be entered for them.

2.7.2.2 Warning and error messages.

```
**** WARNING  **** THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES
                   X AND X (INTERSECTION XX IN ARTERY X AND INTERSECTION
                   XX IN ARTERY X)  IS LESS THAN ONE CYCLE (THERE IS ALL
                   RED TIME OF X.XXXX CYCLES).

**** ERROR  **** NO LOOP1 CARD.

**** ERROR  **** LOWER AND UPPER CYCLE TIMES MUST BE GREATER THAN ZERO.

**** ERROR  **** LOWER CYCLE  LIMIT CANNOT BE  GREATER THAN  UPPER CYCLE
                 LIMIT.

**** ERROR  **** AN INTERSECTION NUMBER  AT ONE OF THE  ARTERY INTERSEC-
                 TIONS IS OUT OF THE ACCEPTABLE RANGE 1 - 16.

**** ERROR  **** ARTERY X SHOULD JOIN ANOTHER  ARTERY AT INTERSECTION XX
                 BUT THIS INTERSECTION IS OUT  OF THE RANGE OF INTERSEC-
                 TIONS ACTUALLY ENTERED.

**** ERROR  **** BAD  LOOP GEOMETRY.   THE SAME  INTERSECTION HAS  BEEN
                 SPECIFIED FOR BOTH MEETINGS OF ARTERY X.

**** ERROR  **** TOTAL OF  SPLITS GIVEN FOR  INTERSECTION OF  ARTERIES X
                 AND X EXCEEDS ONE CYCLE.
```

2.7.3 The LOOP2 Card.

The LOOP2 card contains the target bandwidth ratios (k(4) - k(6)) for the outbound bandwidths of the loop. The card is optional. If it appears, it must be placed immediately after the LOOP1 card. If it is omitted, k(4) - K(6) default to zero.

2.7.3.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION

1-5	-	Word 'LOOP2'	-
11-15	F5.0	Target ratio of outbound bandwidth of artery 2 to outbound bandwidth of artery 1 (k(4)). Range: Must be ≥ 0. If a -1 is entered in this field, k(4) will be computed from volume information. Default: 0.	3.6.5
16-20	F5.0	Target ratio of outbound bandwidth of artery 3 to outbound bandwidth of artery 1 (k(5)). Range: Must be ≥ 0. If a -1 is entered in this field, k(5) will be computed from volume information. Default 0.	3.6.5
21-25	F5.0	Target ratio outbound bandwidth of artery 3 to outbound bandwidth of artery 2 (k(6)). Range: Must be ≥ 0. If a -1 is entered in this field, k(6) will be computed from volume information. Default: 0.	3.6.5

Notes:

1. If any of k(4) - k(6) is to be computed from volume information (i.e., a -1 has been entered in columns 11-15, 16-20 or 21-25, respectively), a VOLUME card must be entered for every intersection analyzed of the two arteries concerned. The numbers of the intersections being analyzed are determined from the values in columns 41-45 and 46-50 of the ARTERY card.
2. If the LOOP2 card is omitted, k(4) - k(6) default to zero.

2.7.3.2 Warning and error messages.

```
****  WARNING  ****  K(4)  IS TO BE SET BUT  VOLUMES ON ARTERY 1 ARE ZERO.
                     K(4) IS ASSUMED ZERO.

****  WARNING  ****  K(5)  IS TO BE SET BUT  VOLUMES ON ARTERY 1 ARE ZERO.
                     K(5) IS ASSUMED ZERO.
```

```
****  WARNING   ****  K(6)  IS TO BE SET BUT  VOLUMES ON ARTERY 1 ARE ZERO.
                      K(6) IS ASSUMED ZERO.
```

Note: These warning messages should never occur if MAXBAND is executing properly.

```
****  ERROR   ****  COMPUTATION OF ONE OF K(4)  - K(6)  HAS BEEN REQUESTED,
                    BUT VOLUME INFORMATION HAS NOT  BEEN PROVIDED FOR EVERY
                    INTERSECTION OF ARTERY X.
```

2.8 CARDS WHICH GIVE INFORMATION ABOUT A SPECIFIC SIGNAL AND ITS APPROACHES (GROUP 5).

2.8.1 The MAP card.

The MAP card contains name and number information for a particular intersection. It must be the first of the group 5 cards to appear for a particular intersection. The MAP card is mandatory.

2.8.1.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-3	-	Word 'MAP'	-
16-20	A5	Node number. Range: Any five character alphanumeric identifier. Default: Blanks.	3.7.1
21-25	I5	Sequence number. Range: 1 - 20 for artery problem 1 - 16 for loop problem. Default: See below.	3.7.1
65-80	A16	Name of cross street at intersection. Range: Any 16 character alphanumeric identifier. Default: Blanks.	3.7.1

Notes:

1. The sequence number is the 'order of entry' number of the intersection. It should be 1 at the first intersection, and go up by 1 at each subsequent intersection. As intersections are entered, MAXBAND generates internal intersection numbers which are compared with the values in columns 21-25. Warning messages are produced if the values do not agree. The user may leave the sequence number field blank, but this will cause a warning message to be printed.

   As explained in section 3.7.1, the internal intersection number, not the sequence number, is the number referred to on the ARTERY and LOOP1 cards.

2.8.1.2 Warning and error messages.

```
****  WARNING  ****  SEQUENCE NUMBER NOT IN ACCEPTABLE RANGE.

****  WARNING  ****  SEQUENCE NUMBER OF FIRST INTERSECTION IS NOT ONE.

****  WARNING  ****  SEQUENCE NUMBERS ARE NOT IN ORDER.

****  ERROR  ****  NO MAP CARD.
```

2.8.2 The SPECIFY card.

The SPECIFY card contains through and left green split information. If this card is present for a intersection, MAXBAND will use the values on it as the preliminary splits of stage 1 of the split derivation process (figure 61). Either the SPECIFY card or the pair of cards VOLUME and CAPACITY must be present for each intersection. The SPECIFY card may be placed anywhere after the MAP card within the group 5 cards for a particular intersection.

2.8.2.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-7	-	Word 'SPECIFY'	-
		The eight split fields:	

16-20	F5.0	Northbound through. Range: Must be ≥ 0 and ≤ 1. Default: Southbound through split (columns 26-30).	3.7.2.1
21-25	F5.0	Northbound left. Range: Must be ≥ 0 and ≤ 1. Default: Southbound left split (columns 31-35).	3.7.2.1
26-30	F5.0	Southbound through. Range: Must be ≥ 0 and ≤ 1. Default: Northbound through split (columns 16-20).	3.7.2.1
31-35	F5.0	Southbound left. Range: Must be ≥ 0 and ≤ 1. Default: Northbound left split (columns 21-25).	3.7.2.1
36-40	F5.0	Eastbound through. Range: Must be ≥ 0 and ≤ 1. Default: Westbound through split (columns 46-50).	3.7.2.1
41-45	F5.0	Eastbound left. Range: Must be ≥ 0 and ≤ 1. Default: Westbound left split (columns 51-55).	3.7.2.1
46-50	F5.0	Westbound through. Range: Must be ≥ 0 and ≤ 1. Default: Eastbound through split (columns 36-40).	3.7.2.1
51-55	F5.0	Westbound left. Range: Must be ≥ 0 and ≤ 1. Default: Eastbound left split (columns 41-45).	3.7.2.1

Notes:

1. Values are entered in fractions of a cycle.

2. MAXBAND only uses the main street splits. However, the user may enter splits for all four directions. This is useful when the intersection is used in more than one artery or is part of a network. In the following points, only the main street splits are referred to.

3. At least one of the outbound and inbound through splits cannot be zero.

4. At least one of the outbound and inbound through split fields cannot be blank. If both left fields are blank, the left splits default to zero.

5. The splits must satisfy the equations

$$\text{maximum } (g(out) + l(in), g(in + l(out)) \leq 1$$

and

$$g(out) + l(in) = g(in) + l(out)$$

where
g(out) is the outbound through split,
g(in) is the inbound through split,
l(out) is the outbound left split,
l(in) is the inbound left split.

These equations result from MAXBAND's split model, and are explained later.

6. Only one SPECIFY card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.2.2 Warning and error messages.

**** WARNING **** A DUPLICATE SPECIFY CARD HAS BEEN READ. IT HAS BEEN IGNORED.

**** WARNING **** THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES X AND X (INTERSECTION XX IN ARTERY X AND INTERSECTION XX IN ARTERY X) IS LESS THAN ONE CYCLE (THERE IS ALL RED TIME OF X.XXXX CYCLES).

**** ERROR **** NO MAIN STREET THROUGH SPLITS GIVEN.

**** ERROR **** NEGATIVE THROUGH SPLIT ENCOUNTERED.

**** ERROR **** NEGATIVE LEFT SPLIT ENCOUNTERED.

**** ERROR **** NO VOLUME, CAPACITY OR SPECIFY CARDS FOR PREVIOUS INTERSECTION.

**** ERROR **** NO SPECIFY OR CAPACITY CARD FOR PREVIOUS INTERESCTION.

**** ERROR **** NO SPECIFY OR VOLUME CARD FOR PREVIOUS INTERSECTION.

**** ERROR **** NO GIVEN SPLITS OR VOLUME OR CAPACITY INFORMATION FOR INTERSECTION XX OF ARTERY X.

Note: This error should never occur if MAXBAND is executing properly.

```
****  ERROR  ****  GIVEN SPLITS EXCEED 100 PER CENT OF CYCLE.

****  ERROR  ****  TOTAL OF  SPLITS GIVEN FOR  INTERSECITON OF  ARTERIES X
                   AND X EXCEEDS ONE CYCLE.
```

2.8.3 The VOLUME card.

The VOLUME card contains information about traffic flow volumes on the approaches to a intersection. If a SPECIFY card is not present for the intersection, this information is used to compute the preliminary splits used in stage 1 of the split derivation process (figure 61). The volume information may also be used for computing target bandwidth ratios (k, k(4) - k(6)) or objective function weights (c(1) - c(6)). Either the SPECIFY card or the pair of cards VOLUME and CAPACITY must be entered for each intersection. The VOLUME card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.3.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-6	-	Word 'VOLUME'	-
		The eight volume fields:	
16-20	F5.0	Northbound through. _Range_: Must be ≥ 0. _Default_: Southbound through volume (columns 26-30).	3.7.2.2
21-25	F5.0	Northbound left. _Range_: Must be ≥ 0. _Default_: Southbound left volume (columns 31-35).	3.7.2.2
26-30	F5.0	Southbound through. _Range_: Must be ≥ 0. _Default_: Northbound through volume (columns 16-20).	3.7.2.2
31-35	F5.0	Southbound left. _Range_: Must be ≥ 0. _Default_: Northbound left volume (columns 21-25).	3.7.2.2

36-40	F5.0	Eastbound through. Range: Must be ≥ 0. Default: Westbound through volume (columns 46-50).	3.7.2.2
41-45	F5.0	Eastbound left. Range: Must be ≥ 0. Default: Westbound left volume (columns 51-55).	3.7.2.2
46-50	F5.0	Westbound through. Range: Must be ≥ 0. Default: Eastbound through volume (columns 36-40).	3.7.2.2
51-55	F5.0	Westbound left. Range: Must be ≥ 0. Default: Eastbound left volume (columns 41-45).	3.7.2.2

Notes:

1. Values are entered in vehicles per hour (vph).
2. MAXBAND requires that volumes be entered for all eight turning movements, not just the main street movements.
3. At least one of the outbound and inbound through volumes cannot be zero on both the main and cross streets.
4. At least one of the outbound and inbound through volume fields cannot be blank on both the main and cross streets. If both left fields are blank, the left volumes default to zero.
5. The values in the fields of the VOLUME card for a particular intersection should be less than the values in the corresponding fields of the CAPACITY card for the same intersection.
6. Only one VOLUME card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.3.2 Warning and error messages.

```
****  WARNING  ****  A DUPLICATE VOLUME  CARD HAS BEEN READ.   IT HAS BEEN
                     IGNORED.

****  WARNING  ****  THERE IS NO VOLUME ON ARTERY X.   IF K, C(1)  OR C(2)
                     ARE TO BE COMPUTED FROM  VOLUME DATA,  THEY HAVE BEEN
                     SET TO ONE.
```

Note: This condition should never occur if MAXBAND is executing properly.

```
****  ERROR  ****  NO THROUGH VOLUME INFORMATION GIVEN FOR AT LEAST ONE OF
                   THE PHASES AT THIS INTERSECTION.

****  ERROR  ****  NEGATIVE THROUGH VOLUME ENCOUNTERED.

****  ERROR  ****  NEGATIVE LEFT VOLUME ENCOUNTERED.

****  ERROR  ****  BOTH VOLUMES  ARE ZERO FOR AT  LEAST ONE PHASE  AT THIS
                   INTERSECTION.

****  ERROR  ****  NO  VOLUME,  CAPACITY  OR  SPECIFY  CARDS FOR  PREVIOUS
                   INTERSECTION.

****  ERROR  ****  NO SPECIFY OR VOLUME CARD FOR PREVIOUS INTERSECTION.

****  ERROR  ****  IT HAS BEEN REQUESTED THAT K, C(1), OR C(2) BE COMPUTED
                   FROM  VOLUME  INFORMATION  FOR ARTERY  X,  BUT  VOLUME
                   INFORMATION HAS  NOT BEEN SUPPLIED FOR  EVERY INTERSEC-
                   TION.

****  ERROR  ****  NO GIVEN SPLITS  OR VOLUME OR CAPACITY  INFORMATION FOR
                   INTERSECTION XX OF ARTERY X.
```

Note: This error should never occur if MAXBAND is executing properly.

```
****  ERROR  ****  COMPUTATION OF ONE OF K(4)  - K(6)  HAS BEEN REQUESTED,
                   BUT VOLUME INFORMATION HAS NOT  BEEN PROVIDED FOR EVERY
                   INTERSECTION OF ARTERY X.

****  ERROR  ****  A  THROUGH VOLUME  EXCEEDS  CAPACITY  AT SIGNAL  XX  IN
                   ARTERY X.

****  ERROR  ****  A LEFT VOLUME  EXCEEDS CAPACITY AT SIGNAL  XX IN ARTERY
                   X.
```

2.8.4 The CAPACITY card.

The CAPACITY card contains information about maximum traffic flow volumes (capacities) on the approaches to a intersection. If a SPECIFY card is not present for the intersection, this information is used to compute the preliminary splits used in stage 1 of the split derivation process (figure 61). Either the SPECIFY card or the pair of cards VOLUME and CAPACITY must be entered for each intersection. The CAPACITY card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.4.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-8	-	Word 'CAPACITY'	-
		The eight capacity fields:	
16-20	F5.0	Northbound through. Range: Must be $\geq$ 0. Default: Southbound through capacity (columns 26-30).	3.7.2.2
21-25	F5.0	Northbound left. Range: Must be $\geq$ 0. Default: Southbound left capacity (columns 31-35).	3.7.2.2
26-30	F5.0	Southbound through. Range: Must be $\geq$ 0. Default: Northbound through capacity (columns 16-20).	3.7.2.2
31-35	F5.0	Southbound left. Range: Must be $\geq$ 0. Default: Northbound left capacity (columns 21-25).	3.7.2.2
36-40	F5.0	Eastbound through. Range: Must be $\geq$ 0. Default: Westbound through capacity (columns 46-50).	3.7.2.2
41-45	F5.0	Eastbound left. Range: Must be $\geq$ 0. Default: Westbound left capacity (columns 51-55).	3.7.2.2
46-50	F5.0	Westbound through. Range: Must be $\geq$ 0. Default: Eastbound through capacity (columns 36-40).	3.7.2.2
51-55	F5.0	Westbound left. Range: Must be $\geq$ 0. Default: Eastbound left capacity (columns 41-45).	3.7.2.2

Notes:

1. Values are entered in vehicles per hour (vph).

2. MAXBAND requires that capacities be entered for all eight turning movements, not just the main street movements.

3. At least one of the outbound and inbound through capacities cannot be zero on both the main and cross streets.

4. At least one of the outbound and inbound through capacity fields cannot be blank on both the main and cross streets. If both left fields are blank, the left capacities default to zero.

5. The values in the fields of the VOLUME card for a particular intersection should be less than the values in the corresponding fields of the CAPACITY card for the same intersection.

6. When splits are computed, any turning movement given a capacity of zero will be given a split of length zero.

7. Only one CAPACITY card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.4.2 Warning and error messages.

**** WARNING **** A DUPLICATE CAPACITY CARD HAS BEEN READ. IT HAS BEEN IGNORED.

**** ERROR **** NO THROUGH CAPACITY INFORMATION GIVEN FOR AT LEAST ONE PHASE AT THIS INTERSECTION.

**** ERROR **** NEGATIVE THROUGH CAPACITY ENCOUNTERED.

**** ERROR **** NEGATIVE LEFT CAPACITY ENCOUNTERED.

**** ERROR **** BOTH CAPACITIES ARE ZERO FOR AT LEAST ONE PHASE AT THIS INTERSECTION.

**** ERROR **** NO VOLUME, CAPACITY OR SPECIFY CARDS FOR PREVIOUS INTERSECTION.

**** ERROR **** NO SPECIFY OR CAPACITY CARD FOR PREVIOUS INTERESCTION.

**** ERROR **** NO GIVEN SPLITS OR VOLUME OR CAPACITY INFORMATION FOR INTERSECTION XX OF ARTERY X.

Note: This error should never occur if MAXBAND is executing properly.

**** ERROR **** A THROUGH VOLUME EXCEEDS CAPACITY AT SIGNAL XX IN ARTERY X.

```
****  ERROR  ****  A LEFT VOLUME  EXCEEDS CAPACITY AT SIGNAL  XX IN ARTERY
                   X.
```

2.8.5 The MINGREEN card.

The MINGREEN card contains minimum values for the splits at a intersection. These values are used to set minimums for the main street splits and for the length of the cross street core time. Since values are entered in fractions of a cycle, care should be taken that they are great enough, in comparison with the minimum cycle length, to provide the minimum splits and cross street core time desired in seconds. The MINGREEN card is optional. If it is entered, the preliminary splits of stage 1 of the split derivation process (figure 61) will be modified according to its values, regardless of whether the splits were obtained from the SPECIFY card or computed from the values on the VOLUME and CAPACITY cards. The MINGREEN card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.5.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-8	-	Word 'MINGREEN'	-
		The eight minimum green fields:	
16-20	F5.0	Northbound through. Range: Must be $\geq$ 0. Default: Southbound through minimum green (columns 26-30).	3.7.2.3
21-25	F5.0	Northbound left. Range: Must be $\geq$ 0. Default: Southbound left minimum green (columns 31-35).	3.7.2.3
26-30	F5.0	Southbound through. Range: Must be $\geq$ 0. Default: Northbound through minimum green (columns 16-20).	3.7.2.3
31-35	F5.0	Southbound left. Range: Must be $\geq$ 0. Default: Northbound left minimum green (columns 21-25).	3.7.2.3

36-40	F5.0	Eastbound through. Range: Must be $\geq$ 0. Default: Westbound through minimum green (columns 46-50).	3.7.2.3
41-45	F5.0	Eastbound left. Range: Must be $\geq$ 0. Default: Westbound left minimum green (columns 51-55).	3.7.2.3
46-50	F5.0	Westbound through. Range: Must be $\geq$ 0. Default: Eastbound through minimum green (columns 36-40).	3.7.2.3
51-55	F5.0	Westbound left. Range: Must be $\geq$ 0. Default: Eastbound left minimum green (columns 41-45).	3.7.2.3

Notes:

1. Values are entered in fractions of a cycle.

   Because of this, the values should be selected in conjunction with the minimum cycle time to insure that the minimum splits desired in seconds will be obtained.

2. The minimum green times entered for the main street split are used directly to modify these splits in stage 2 of the split derivation process (figure 61). Since MAXBAND only uses the main street splits on a particular artery, the cross street splits are not available to be modified. Hence the cross street minimum green times are used only to establish a minimum length for the cross street core time. If the user does not wish to increase the length of the cross street core time, he or she may enter minimum green times for only the main street splits. The cross street minimum green times will then default to zero.

3. If the MINGREEN card has been omitted and splits have been computed from volume and capacity information, default minimum green times of 0.05 are used for all the main street splits whose capacities are greater than zero.

4. The minimum green times must satisfy the equation

$$\begin{gathered}\text{maximum}\ (\text{ming}(nb) + \text{minl}(sb), \text{ming}(sb) + \text{minl}(nb)) \\ + \\ \text{maximum}\ (\text{ming}(eb) + \text{minl}(wb), \text{ming}(wb) + \text{minl}(eb)) \\ \leq 1\end{gathered}$$

where

nb, sb, wb and wb are the four directions,
ming(i) is the minimum through green time in direction i, and
minl(i) is the minimum left green time in direction i.

5. If both a field and the field from which it takes its default value are blank, the corresponding minimum greens default to zero.

6. Only one MINGREEN card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.5.2 Warning and error messages.

```
****  WARNING  ****  A DUPLICATE MINGREEN CARD HAS BEEN READ.  IT HAS BEEN
                     IGNORED.

****  ERROR  ****  NEGATIVE THROUGH MINIMUM GREEN TIME ENCOUNTERED.

****  ERROR  ****  NEGATIVE LEFT MINIMUM GREEN TIME ENCOUNTERED.

****  ERROR  ****  TOTAL OF MINIMUM GREEN TIMES EXCEEDS ONE CYCLE.
```

2.8.6 The LEFTPAT card.

The LEFTPAT card indiates which set of the four possible left turn patterns shown in figure 13 (which is the same as figure 28 of chapter 3) should be considered by MAXBAND at a particular intersection. The card is optional. If the LEFTPAT card is omitted, the set of permitted left turn patterns will be chosen as noted below. The LEFTPAT card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.6.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-7	-	Word 'LEFTPAT'	-
		The four pattern choice fields:	

11-15	I5	Pattern 1. Values: 0 - Pattern not considered 1 - Pattern considered. Default: Pattern not considered.	3.7.4
16-20	I5	Pattern 2. Values: 0 - Pattern not considered 1 - Pattern considered. Default: Pattern not considered.	3.7.4
21-25	I5	Pattern 3. Values: 0 - Pattern not considered 1 - Pattern considered. Default: Pattern not considered.	3.7.4
26-30	I5	Pattern 4. Values: 0 - Pattern not considered 1 - Pattern considered. Default: Pattern not considered.	3.7.4

Notes:

1. A 1 entered in a field indicates that that pattern should be among those considered by MAXBAND.

2. If a value other than 1 is entered in a field, the corresponding pattern is not considered

3. If only one left split is nonzero, the four left turn patterns are reduced to two. In the output, MAXBAND always calls these patterns 1 and 2.

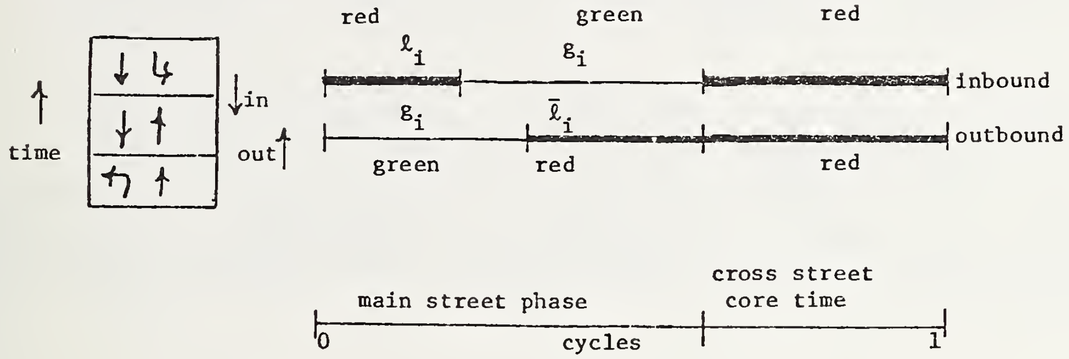
4. If the LEFTPAT card is omitted, but both left turn splits are nonzero, all four left turn patterns will be considered.

5. If the LEFTPAT card is omitted, but exactly one left turn split is nonzero, left turn patterns 1 and 2 will be considered.

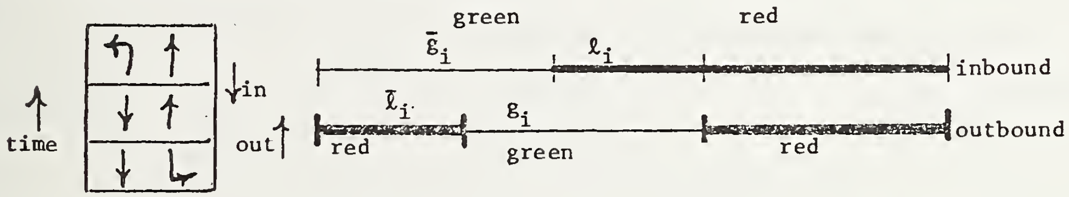
6. If the LEFTPAT card is omitted, and no left turn splits are nonzero, no left turn patterns will be considered.

7. Only one LEFTPAT card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

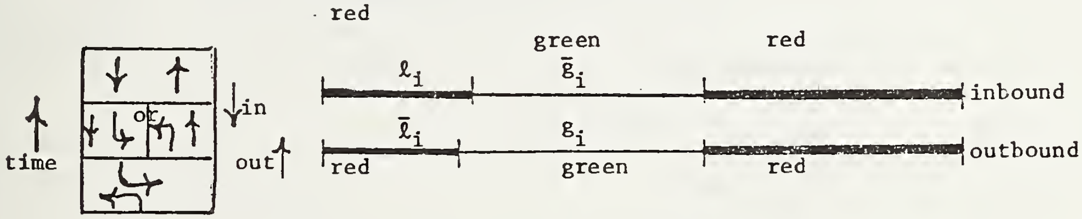
1. Outbound left leads, inbound lags



2. Outbound left lags; inbound leads



3. Outbound left leads; inbound leads



4. Outbound left lags; inbound lags

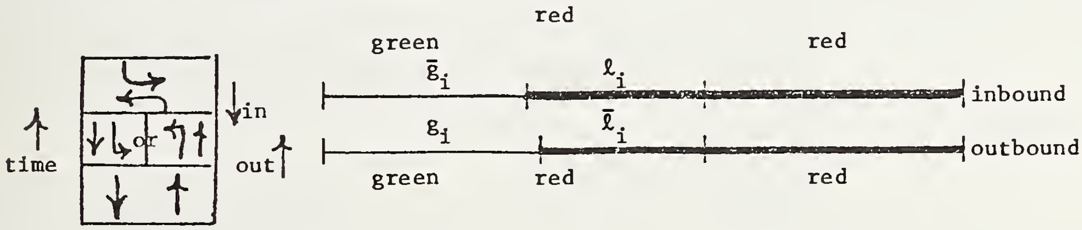


Figure 13: The four left turn patterns.

2.8.6.2 Warning and error messages.

```
****  WARNING  ****  A DUPLICATE LEFTPAT CARD HAS  BEEN READ.  IT HAS BEEN
                     IGNORED.

****  WARNING  ****  BAD VALUE ENCOUNTERED IN LEFTPAT CARD.  ASSUMED TO BE
                     ZERO.
```

2.8.7 The LENGTH card.

The LENGTH contains the lengths of the approaches to a particular intersection (links). It is mandatory. The LENGTH card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.7.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-6	-	Word 'LENGTH'	-
		The four length fields:	
16-20	F5.0	Northbound. Range: Must be > 0. Default: See below.	3.7.5
26-30	F5.0	Southbound. Range: Must be > 0. Default: See below.	3.7.5
36-40	F5.0	Eastbound. Range: Must be > 0. Default: See below.	3.7.5
46-50	F5.0	Westbound. Range: Must be > 0. Default: See below.	3.7.5

Notes:

1. Values are entered in feet or meters, depending on the units selected in column 40 of the SETUP, SETUP1, SETUP2 or SETUP3 card.

2. A value for the outbound approach length must always be entered, with the exception noted below.

3. The field for the length of the inbound approach to a intersection may be left blank. The length of this approach will then default to the length of the outbound approach to the next intersection.

4. MAXBAND does not the use the lengths of the outbound approach to the first intersection, or the inbound approach to the last intersection. The fields for these values may be left blank, or values of zero may be entered for either length.

5. Only one LENGTH card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.7.2 Warning and error messages.

**** WARNING **** A DUPLICATE LENGTH CARD HAS BEEN READ. IT HAS BEEN IGNORED.

**** ERROR **** NO LENGTH VALUES GIVEN.

Note: This means that the outbound length field was blank on a LENGTH card for a intersection other than the first.

**** ERROR **** ZERO OR NEGATIVE LENGTH ENCOUNTERED.

**** ERROR **** NO LENGTH CARD FOR PREVIOUS INTERSECTION.

2.8.8 The SPEED card.

The SPEED card is used to override the artery wide values established for the artery design speed and artery design speed tolerances on the ART2 card on a particular intersection approach. The SPEED card is optional. The SPEED card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.8.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION

1-5	-	Word 'SPEED'	-
16-20	F5.0	Northbound design speed. Range: Must be > 0 and see below. Default: See below.	3.7.6
21-25	F5.0	Northbound design speed tolerance. Range: Must be ≥ 0 and see below. Default: See below.	3.7.6
26-30	F5.0	Southbound design speed. Range: Must be > 0 and see below. Default: See below.	3.7.6
31-35	F5.0	Southbound design speed tolerance. Range: Must be ≥ 0 and see below. Default: See below.	3.7.6
36-40	F5.0	Eastbound design speed. Range: Must be > 0 and see below. Default: See below.	3.7.6
41-45	F5.0	Eastbound design speed tolerance. Range: Must be > 0 and see below. Default: See below.	3.7.6
46-50	F5.0	Westbound design speed. Range: Must be ≥ 0 and see below. Default: See below.	3.7.6
51-55	F5.0	Westbound design speed tolerance. Range: Must be ≥ 0 and see below. Default: See below.	3.7.6

Notes:

1. Values are entered in miles per hour (mph) or kilometers per hour (kph), depending on the units indicated in colum 40 of the SETUP, SETUP1, SETUP2 or SETUP3 card.

2. There are no defaults. Only values actually entered on the SPEED card are used to override the artery wide values entered on the ART2 card. If a field is left blank, the corresponding design speed or design speed tolerance will default to the artery wide value.

3. Values entered on the SPEED card must satisfy the same constraints as do the artery wide values entered on the ART2 card.

4. If the SPEED card is omitted, the artery wide values entered on the ART2 card will be used on the approaches to the intersection.

5. Only one SPEED card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.8.2 Warning and error messages.

**** WARNING **** A DUPLICATE SPEED CARD HAS BEEN READ. IT HAS BEEN IGNORED.

**** ERROR **** ZERO OR NEGATIVE SPEED ENCOUNTERED.

**** ERROR **** NEGATIVE TOLERANCE ENCOUNTERED.

**** ERROR **** TOLERANCE IS GREATER THAN DESIGN SPEED ALONG SOME LINK OF ARTERY X.

**** ERROR **** CHANGE VALUE EXCEEDS OR EQUALS THE MINIMUM OF UPPER SPEED LIMITS OF LINK ALONG ARTERY X.

**** ERROR **** A CHANGE OF SPEED VALUE IS NOT LARGE ENOUGH ON ARTERY X.

2.8.9 The QUEUE card.

The QUEUE card allows the user to advance the outbound and inbound bandwidths to compensate for queues at a particular intersection. The card is optional. The QUEUE card may be placed anywhere after the MAP card within the group 5 five cards for a particular intersection.

2.8.9.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-5	-	Word 'QUEUE'	-
		The four queue clearance fields:	

16-20	F5.0	Northbound. Range: Must be ≥ 0 and ≤ 1. Default: Southbound queue clearance time (columns 26-30).	3.7.7
26-30	F5.0	Southbound. Range: Must be ≥ 0 and ≤ 1. Default: Northbound queue clearance time (columns 16-20)..	3.7.7
36-40	F5.0	Eastbound. Range: Must be ≥ 0 and ≤ 1. Default: Westbound queue clearance time (columns 36-40).	3.7.7
46-50	F5.0	Westbound. Range: Must be ≥ 0 and ≤ 1. Default: Eastbound queue clearance time (columns 46-50).	3.7.7

Notes:

1. Values are entered in fractions of a cycle.
2. Only two of these fields will be needed on any particular artery.
3. If both fields used at a intersection are blank, the corresponding queue clearance times default to zero.
4. Only one QUEUE card is used at each intersection. If more than one is entered for a intersection, all but the first are ignored.

2.8.9.2 Warning and error messages.

```
****  WARNING  ****  A DUPLICATE  QUEUE CARD HAS  BEEN READ.  IT  HAS BEEN
                     IGNORED.

****  ERROR  ****  QUEUE CLEARANCE TIME NEGATIVE OR GREATER THAN ONE.
```

2.9 OTHER CARDS (GROUP 6).

2.9.1 The COMM card.

The COMM card is used to place comments in the input deck. The card may be placed anywhere in the input deck. It will be printed with the other input cards in the Input Card section of the output. However, it will not be printed if it placed after the END card.

2.9.1.1 Input fields.

COLUMNS	READ IN FORMAT	DESCRIPTION	DESCRIBED IN SECTION
1-4	-	Word 'COMM'	-
9-80	-	Comment.	3.9

2.9.1.2 Warning and error messages.

None.

Chapter 3

USING MAXBAND

This chapter introduces the MAXBAND system. It is intended to be used in conjunction with chapter 2: MAXBAND Input Cards, chapter 4: MAXBAND Examples and chapter 5: MAXBAND Output.

Chapter 3 describes MAXBAND data requirements and capabilities. The headings of sections discussing MAXBAND input cards are followed by the name of the card and the columns of the card involved in parentheses.

The MAXBAND system has some sophisticated features which the beginning user may wish to ignore on first reading. Sections marked by double asterisks (**) are concerned with advanced features and may be skipped by the new user.

For a complete understanding of the use of the SPECIFY, VOLUME, CAPACITY, MINGREEN and LEFTPAT cards, the user should be familiar with MAXBAND's split model and the process by which MAXBAND obtains the splits used in the problem formulation. These are explained in appendix D.

3.1 THE MAXBAND INPUT DECK AND INPUT CARDS.

The general formats for artery and loop input decks is shown in figures 9 and 10 of chapter 2.

The cards are divided into the 6 functional groups shown in figure 11 of chapter 2. All MAXBAND cards are 80 characters long. The name of the card begins in column 1 and must appear exactly as shown in figures 9 or 10 and 11. In the following discussion, it is assumed that the remaining portion of the card is to be blank, except where a field and its value has been specifically mentioned. Numbers must be entered right-justified into all numeric fields. Unless otherwise stated, all entries described below are mandatory.

3.2 BEGINNING THE JOB (START).

All decks must begin with the START card. Normally columns 6-80 of the card will be blank, as in the sample of figure 14. To use the START card to control output level and execution, see the next section.

1 8		15	20	25	30	35	40	45	50	55	56		65 80
		*	*										
START													

* indicates fields used on the START card

Figure 14: Sample START card.

3.3 CONTROLLING THE AMOUNT OF OUTPUT (START -- COLS. 11-15 AND 16-20). **

MAXBAND allows the user to control the amount of output by using columns 11-15 and 16-20 of the START card. The corresponding values are called, respectively, the 'message level' and the 'warning level'. The use of the START card for controlling the amount of output is fully explained in the 'Controlling types of output' section of chapter 5.

3.4 SETTING OPERATING PARAMETERS FOR MPCODE (MPCODE -- COLS. 11-20 TO 31-35). **

MAXBAND uses the maximization routine, MPCODE, to optimize its formulations of the artery and loop problems. In finding the optimal solution, MPCODE solves a large number of subordinate linear programs. Each of these, in turn, requires a certain number of steps, or iterations, for solution. In addition, MPCODE occasionally performs a procedure called a 'reinversion', which allows it to maintain the accuracy of its representation of the MAXBAND formulation. In the 'MPCODE Statistics' portion of the output (see Chapter 5), MAXBAND indicates

1. How many iterations the entire maximization routine required;

2. The largest number of iterations required by a single linear program;

3. How many reinversions were performed during the entire maximization routine; and

4. The largest number of reinversions performed during a single linear program.

MAXBAND allows the user to specify upper limits on the size each of these four quantities can attain during the performance of the maximization routine. This is done by entering values in the appropriate fields of the MPCODE card. These fields are:

columns 11-20 MAXRBB -- limit on total maximization iterations
columns 21-25 MAXIBB -- limit on total maximization reinversions
columns 26-30 MAXITR -- limit on iterations by a single linear program
columns 31-35 MAXINV -- limit on reinversions by a single linear program

If the MPCODE card is not used, or some of its fields are left blank, MAXBAND uses these defaults for parameters for which no value has been entered:

MAXRBB - 10000
MAXIBB - 100
MAXITR - 1000
MAXINV - 100

Note: See the 'RESTARTING' section of this chapter for an additional use of the MPCODE card.

3.4.1 Setting MAXIBB, MAXITR and MAXINV. **

If one of MAXIBB, MAXITR, or MAXINV is exceeded, the maximization routine halts, a message is printed in the MAXBAND output, and the program halts. In this situation, MPCODE cannot be restarted from the point at which it has halted, so if the best solution found by MPCODE so far still has too small a bandwidth, it is necessary to increase the limit which caused the halt, and start the program over again from the beginning. Since this can entail extra expense, MAXIBB, MAXITR, and MAXINV need to be made sufficiently large so that they have a margin of error in excess of the largest problem values expected. The default values for MAXIBB, MAXITR and MAXINV should be adequate in almost all situations. However, after examining the 'MPCODE Statistics' portion of the output for several problems, the user may wish to change these parameters to more closely reflect the size of problem usually worked with.

3.4.2 Setting MAXRBB. **

If the maximization routine is about to exceed MAXRBB iterations, it writes the current state of the problem to a MAXBAND output file, and prints a message in the MAXBAND output. This is called 'punching a node'. The contents of this 'node' file can be used later to restart MPCODE at the point where it has halted, saving the work already done. Since the total number of iterations required by MPCODE to solve a problem increases rapidly as the number of signals increases, and the cost of solving a MAXBAND problem is closely tied to the number of iterations required, the user may wish to tailor the value of MAXRBB. MAXRBB should be large enough so that there is a reasonable number of iterations available in excess of those likely to be required by the largest problems normally run, but that a problem which requires an unusually large amount of computer resources will be stopped before it has run too long. Such a problem will be able to resume running from where it left off, when and if restarted. In this way, the user can prevent wastage of computer resources.

The limit of 10000 iterations is probably sufficient for singly artery problems of 10 of fewer signals. For larger problems of 11-20 signals, a limit of 30000 iterations is recommended. For loop problems, a limit of 25000 iteratons is probably sufficient for problems of 3-10 signals. For problems of 11-17 signals, a limit of 100000 iterations is suggested.

1 8		15 *	20 *	25 *	30 *	35 *	40 *	45	50	55	56		65 80
MPCODE			15000	150									

* indicates fields used on the MPCODE card

Figure 15: A sample MPCODE card.

Figure 15 shows a sample MPCODE card. MAXRBB has been set to 15000, MAXIBB has been set to 150, and MAXITR and MAXINV have been allowed to default to 1000 and 100, respectively.

3.5 INTRODUCING AN ARTERY.

The group 3 cards of figure 11 introduce an artery. In the single artery deck, this group begins with the SETUP card and indicates that the problem is an artery problem, as well as giving general artery information. In the loop deck, the group gives general artery information about a specific artery. In the loop deck, it is repeated three times, beginning with the SETUP1, SETUP2, SETUP3 cards, respectively. The use of the group 3 cards in the single artery and loop cases is almost identical, with the exceptions noted below.

3.5.1 Indicating the number of intersections in the artery (SETUP -- cols. 19-20).

The number of intersections in the artery is entered in columns 19-20 of the SETUP, SETUP1, SETUP2 or SETUP3 card. In the single artery problem, there must be at least 2 intersections but not more than 20. In the loop problem, there must be at least 2 but not more that 16 intersections in each artery. The total number of intersections for all three arteries in the loop problem cannot exceed 17.

3.5.2 Indicating Metric or English units (SETUP -- col. 40).

MAXBAND uses one set of units throughout an artery. The choice is indicated in column 40 of the SETUP, SETUP1, SETUP2 or SETUP3 cards. A 0 indicates that English (feet, miles per hour) units are to be used. A 1 indicates that metric (meters, kilometers per hour) units are to be used. If this field is left blank, or a value other than 1 appears, English units are assumed. In the loop problem, it is possible to use one type of unit on one artery, and the other type on the other arteries.

3.5.3 Direction of entry (SETUP -- col. 56).

Throughout this manual, the two directions of flow along the artery are referred to as outbound and inbound. Using the order of intersection entry, the outbound direction is defined as the one towards which intersections are successively entered, and the inbound direction as the one from which the intersections are entered. Hence moving from the first intersection entered to the second is moving in the outbound direction.

MAXBAND requires that the outbound and inbound directions on the artery be associated with a map direction. The letter N, S, E, or W is entered in column 56 of the SETUP card to indicate from which direction the intersections are entered (i.e., the inbound direction). Column 56 cannot be left blank and must contain one of the four direction letters indicated above. The principal use of the direction of entry is to determine which fields of the signal specific (group 5) cards have the outbound and inbound data for the artery.

In the loop problem, it is impossible, because of the geometry of the loop and the intersections, to assign map directions to the three arteries so that one street runs N-S and the other street runs E-W at each of the three artery meetings. However, since the three arteries are entered separately, there should be no problem in specifying to which street entered data applies at each of the three artery meetings.

This feature is also intended to facilitate the analysis of arteries which are part of a network of streets. The beginning user, or the user who is primarily analyzing independent arteries, may wish to standardize intersection data entry by always using the same direction of entry, regardless of the real orientation of the street. For example, an entry direction of S will enable the user to use the first 4 fields of the SPECIFY, VOLUME, CAPACITY and MINGREEN cards as the two outbound fields and the two inbound fields, repsectively, when entering data.

3.5.4 Naming the artery (SETUP -- cols. 65-80).

A 16 character identifier for the artery may be entered in columns 65-80 of the SETUP, SETUP1, SETUP2 or SETUP3 card. This field may be left blank if desired.

3.5.5 SETUP card example.

Figure 16 shows a sample SETUP card. The card indicates that the artery has 6 intersections, is identified as 'SAMPLE 1', has English units and is entered from the south.

3.5.6 Cycle time limits (ARTERY -- cols. 11-15 and 16-20).

In a single artery problem, MAXBAND will find a solution with a common cycle time for all intersections in the artery. The lower and upper limits within which this time must lie, in seconds, are entered in columns 11-15 and 16-20, respectively, of the ARTERY card. Both values must be greater than zero, and the lower limit must be less than or equal to the upper limit. Both limits must be entered. The user may indicate that MAXAND find a solution with a certain cycle time by entering the same value for both the lower and upper limits.

In the loop problem, one set of cycle time limits is used for all three arteries. These are entered on the LOOP1 card (see below). Any values entered in columns 11-15 and 16-20 of the individual ARTERY cards are ignored.

1 8		15	20 *	25	30	35	40 *	45	50	55	56 *		65 80 *
SETUP			6				0				S		Sample 1

* indicates fields used on the SETUP card

Figure 16: A sample SETUP card.

Important: In MAXBAND, minimum green times are entered in fractions of a cycle. Care must be taken in selecting a lower cycle limit that it is large enough to provide the minimum green times desired in seconds. If splits at an intersection are computed from volume and capacity information, but no MINGREEN card is entered, MAXBAND will use default minimum green times of 0.05 cycles.

3.5.7 Using only some of the intersections entered (ARTERY -- cols. 41-45 and 46-50). **

On occasion, the user may wish to include only some of the intersections entered in the input deck in the artery analysis. In columns 41-45 and 46-50 of the ARTERY card, the user may specify the first and last, respectively, of the entered intersections to be used. These values must be in the range 1 to n, where n is the total number of intersections entered. If columns 41-45 are left blank, analysis begins with the first intersection entered. If columns 46-50 are left blank, analysis ends with the last intersection entered.

This feature is useful when the artery to be entered is part of a larger network, or when the user wishes to analyze a smaller portion of a previously analyzed artery, without making major changes in the input deck.

3.5.8 ARTERY card examples.

Figure 17 shows a simple use of the ARTERY card. The card gives cycle time limits of 30 and 120 seconds. Since columns 41-45 and 46-50 are blank, analysis begins with the first intersection entered and ends with the last.

1 8		15 *	20 *	25	30	35	40	45 *	50 *	55	56		65 80
ARTERY		30	120										

* indicates fields used on the ARTERY card

Figure 17: A simple use of the ARTERY card.

In figure 18, the same cycle times have been entered, but columns 41-45 and 46-50 indicate that only the second through the fifth of the six signals entered will be included in the artery analysis.

3.5.9 Controlling relative importance of outbound and inbound bandwidths (ART2 -- cols. 11-15, 16-20 and 21-25). **

MAXBAND has several user controlled quantities which can be used to control the amount of emphasis which is placed on each of the two bandwidths of an artery.

First, for each artery, there is a quantity called the target bandwidth ratio, or k. k is the ratio the user desires to establish between the inbound and outbound bandwidths. It is a 'target' because it is not guaranteed, but worked toward as MPCODE maximizes the problem formulation.

MAXBAND enters k in the problem formulation by setting up one of the

1 8		15	20	25	30	35	40	45	50	55	56		65 80
		*	*					*	*				
ARTERY		30	120					2	5				

* indicates fields used on the ARTERY card

Figure 18: A more advanced use of the ARTERY card.

three equations:

$$
\begin{array}{ll}
b(2) \leq kb(1) & \text{if } k > 1 \\
b(2) \geq kb(1) & \text{if } k < 1 \\
b(2) = b(1) & \text{if } k = 1
\end{array}
$$

where b(1) and b(2) are the outbound and inbound bandwidths of the artery. In the loop case, one of these equations is entered for each artery, using the target bandwidth ratio and bandwidths of that particular artery.

Second, associated with each artery are two quantities called the objective function weights, c(1) and c(2). MAXBAND solves problems by using the maximization routine MPCODE. c(1) and c(2) appear in a linear expression, called the objective function, which MPCODE attempts to maximize while satisfying other equations which define the problem. In the single artery case, this expression is

$$c(1)b(1) + c(2)b(2)$$

where b(1) and b(2) are the outbound and inbound bandwidths, respectively, of the artery. In the loop case, this expression is expanded to

$$
\begin{array}{l}
c(1)b(1) + c(2)b(2) + c(3)b(3) \\
+ c(4)b(4) + c(5)b(5) + c(6)b(6)
\end{array}
$$

where b(1), b(3) and b(5) are the outbound bandwidths of arteries 1, 2 and 3, respectively; b(2), b(4) and b(6) are the inbound bandwidths; and c(1) - c(6) are the corresponding objective function weights. Note, however, that in the output of the loop case, MAXBAND still refers to the outbound and inbound objective function weights of each artery as c(1) and c(2).

The maximization routine will attempt to find a problem solution which assigns larger values to bandwidths having larger objective function weights, and smaller values to bandwidths with smaller weights.

In general, k is a more important determinant of final bandwidth ratio than c(1) and c(2). The target ratio k will usually be acheived by the maximization routine unless larger bandwidths would result from some other ratio. The best results are usually obtained when

$$k = c(2)/c(1).$$

3.5.9.1 Entering values for k, c(1) and c(2). **

The user may enter values independently for each of k, c(1) and c(2). However, for best results, the three quantities should be related in the manner discussed in the next subsection.

For each of k, c(1) and c(2), the user has the choice of

1. Giving a specific value for the quantity;
2. Allowing it to default to 1 (Note: Both c(1) and c(2) must default to 1 if this choice is made); or
3. Indicating that it should be computed from volume information.

If the user follows option 2 for all three quantities, MAXBAND will automatically establish the desired relationship

$$k =c(2)/c(1)$$

as k, c(1) and c(2) will all be 1. In this case, the outbound and inbound bandwidths will be made equal.

If the user follows option 3 for all three quantities, k is computed as the ratio of inbound to outbound traffic volume on the artery, and c(1) and c(2) are given the fractions of the traffic volume in the outbound and inbound directions, respectively, of the artery. In this case, the relationship

$$k = c(2)/c(1)$$

is also acheived.

Following choice 1, the user may enter his or her own values for k, c(1) and c(2) if volume information is not available, or if the user wishes to establish some bandwidth ratio independently of traffic volume.

Note that MAXBAND never checks for a satisfactory relationship between the values of k, c(1) and c(2) it obtains. This is the responsibility of the user.

The value of k is controlled by columns 11-15 of the ART2 card, and may be specified three ways:

1. Columns 11-15 of the ART2 card are left blank. k then defaults to 1.

2. A non-negative number is entered in columns 11-15 of the ART2 card. This value is then assigned to k.

3. A -1 is entered in columns 11-15 of the ART2 card. k will then be computed as

$$k = \begin{cases} \text{AIVOL} / \text{AOVOL} & \text{if AOVOL} > 0 \\ 1 & \text{if AOVOL} = 0 \end{cases}$$

The user controls the values used for c(1) and c(2) in the single artery case, or the pair of weights (c(1) and c(2), or c(3) and c(4), or c(5) and c(6)) corresponding to the current artery bandwidths in the loop case, by entering values in columns 16-20 and 21-25 of the ART2 card. There are three ways this may be done. For simplicity we refer to the outbound and inbound weights for both the single artery and the loop cases as c(1) and c(2):

1. Columns 16-20 and 21-25 of the ART2 card are left blank. c(1) and c(2) then default to 1.

2. The user enters values for c(1) and c(2) in columns 16-20 and 21-25, respectively, of the ART2 card. These values must be greater than or equal to zero. Note that the user may enter a value in just one field. If the other field is left blank, the weight corresponding to the blank field is set to the weight which has been entered.

3. The user places a -1 in one or both of these fields. This indicates that the corresponding weight should be computed from artery traffic volumes. This requires that the user enter a VOLUME card for each intersection used in the artery. If columns 16-20 contain -1, c(1) is computed as

$$c(1) = \begin{cases} 2 \times \dfrac{\text{AOVOL}}{\text{AOVOL} + \text{AIVOL}} \\ \quad \text{if AOVOL} + \text{AIVOL} > 0 \\ 1 \quad \text{if AOVOL} + \text{AIVOL} = 0 \end{cases}$$

where AOVOL = average traffic volume in vehicles per hour on outbound approaches (mean of outbound values on all VOLUME cards for intersections used in artery),

AIVOL = average traffic volumes in vehicles per hour on inbound approaches (mean of inbound values on all VOLUME cards for intersections used in artery).

If columns 21-25 of the ART2 card contain -1, c(2) is computed as

$$c(2) = \begin{cases} 2 \times \dfrac{\text{AIVOL}}{\text{AOVOL} + \text{AIVOL}} & \text{if AOVOL + AIVOL} > 0 \\ 1 & \text{if AOVOL + AIVOL} = 0 \end{cases}$$

As in 2., the user may enter a -1 in only one field. If the other field is left blank, the corresponding weight will be set the value of the weight entered. Note that it is possible to use both methods 2. and 3., by giving a value for one coefficient and computing the value for the other.

3.5.9.2 Establishing the proper relationship between k, c(1) and c(2). **

No matter which method is chosen to enter the values for the three quantities, in order to insure reasonable solutions, a certain relationship should be maintained between the target bandwidth ratio, k, and the objective function weights, c(1) and c(2), on each artery. Since MAXBAND does not check the relationship between the values it obtains for k, c(1) and c(2), this is the responsibility of the user. (recall that in the loop case, c(1) and c(2) refer to each of the pairs c(1) and c(2), or c(3) and c(4), or c(5) and c(6), while k refers to each of the corresponding target bandwidth ratios.)

As stated above, the best results are usually obtained when k = c(2)/c(1). If traffic volumes are known, then c(1) and c(2) should be assigned values such that c(2)/c(1) is the ratio of inbound traffic flow to outbound traffic flow, and k should be assigned c(2)/c(1).

However, MAXBAND provides the user with the capability to enter other values than these for k, c(1) and c(2). To insure reasonable results, the user should be sure in entering values that

1. If $k < 1$, then $c(2) < c(1)$.

2. If $k > 1$, then $c(2) > c(1)$.

The reason is as follows: If $k < 1$, but $c(2) > c(1)$, MAXBAND sets up the equation

$$b(2) \geq kb(1)$$

and the objective function

$$c(1)b(1) + c(2)b(2) \quad \text{where } c(2) > c(1).$$

Because of the nature of the maximization routine, it will attempt to make the inbound bandwidth, b(2), as large as possible, if necessary, assigning the outbound bandwidth, b(1), a zero value. This result, which can occur even if c(2) is only slightly larger than c(1), may be quite different from what the user intended.

The problem of establishing the correct relationship between k, c(1) and c(2) can be handled in several ways:

1. The user can leave the k, c(1) and c(2) fields of the ART2 card blank. k, c(1) and c(2) will then all default to one.

2. The user can enter -1's in the k, c(1) and c(2) fields of the ART2 card. k, c(1) and c(2) will then be computed from volume information using the above formulas. These formulas automatically establish the proper relationship between the three quantities, i.e. k = c(2)/c(1).

3. The user can enter explicit values for k, c(1) and c(2) such that points 1 and 2 above are satisfied. k, c(1) and c(2) such that k = c(2)/c(1) are such values.

3.5.10 Speed limits to be used throughout the artery (ART2 -- cols. 26-30 to 51-55).

MAXBAND requires that the user specify a design speed, a tolerance on this design speed, and a limit on the change in speed allowed between consecutive approaches, for both the outbound and inbound direction of an artery. The design speeds and tolerances are used as default values on the artery links, and may be overridden on a specific approach by a SPEED card. These values are entered in miles per hour (mph) or kilometers per hour (kph), according to the units specified on the SETUP, SETUP1, SETUP2 or SETUP3 card. The MAXBAND solution will contain progression speeds on each link of the artery (outbound and inbound) which satisfy the speed contraints.

The outbound and inbound design speeds are entered in columns 26-30 and columns 41-45, respectively, of the ART2 card. The design speed for at least one of the two directions must be entered. Values entered must be greater than zero. If the field for one direction is left blank, both speeds will be set to the one value entered. These design speeds will be used on every outbound or inbound approach link in the artery. The user may assign other values for the design speed on particular links by using the SPEED card.

The outbound and inbound tolerances on the design speed are entered in mph or kph in columns 31-35 and 46-50, respectively, of the ART2 card. These values must greater than or equal to zero. Either field or both fields may be left blank, in which cases, the outbound tolerance defaults to 10 per cent of the outbound design speed, and the inbound tolerance defaults to 10 percent of the inbound design speed. These tolerances will be used throughout the artery unless overridden on a specific link by the SPEED card.

The allowed change in speed between consecutive links is entered in columns 36-40 of the ART2 card for the outbound direction, and columns 51-55 of the same card for the inbound direction. The values entered must be greater than or equal to zero. If either field, or both fields, is left blank, the corresponding change limit will be set to the value of the design speed tolerance in the same direction.

In addition to the restrictions noted above, there are several others which the speed values entered on the ART2 card must satisfy. In each direction:

1. The design speed tolerance cannot be larger than the design speed along any link.

2. The change in speed allowed between links cannot be larger than the smallest value of

   design speed + design speed tolerance

   for all the links

3. The range

   (design speed - design speed tolerance
   - allowed change in speed between links,
   design speed + design speed tolerance
   + allowed change in speed between links)

   on one link must overlap the range

   (desgin speed - design speed tolerance,
   desgin speed + design speed tolerance)

   on the next link.

3.5.11 ART2 card examples.

Figure 19 shows the ART2 card for a simple artery problem. An outbound design speed of 20 miles per hour has been entered. Since the remaining fields are left blank, the inbound design speed is also 20 mph, the outbound and inbound speed tolerances are 2 mph , and the allowed changes in speed between links in both outbound and inbound directions are 2 mph. The target bandwidth ratio (k) and the objective function weights, c(1) and c(2), are 1, as the appropriate data items have been left blank.

In figure 20 some of the more advanced features of the ART2 card have been used. The card indicates, first, that the target bandwidth ratio (k) is to be computed from volume information. This means that a VOLUME card

1 8	15 *	20 *	25 *	30 *	35 *	40 *	45 *	50 *	55 *	56	65 80
ART2				20							

* indicates fields used on the ART2 card

Figure 19: Using the ART2 card in a simple artery problem.

must be entered for each intersection included in the analysis. These would be the second through the fifth intersections if the ARTERY card of figure 18 were used. Second, outbound design speed is 20 mph, with a tolerance of 5 mph, and inbound design speed is 25 mph, with the same tolerance. The allowed changes in speed between links for both directions are 2 mph.

1 8	15 *	20 *	25 *	30 *	35 *	40 *	45 *	50 *	55 *	56	65 80
ART2	-1	.6	1.2	20	5	2	25	5	2		

* indicates fields used on the ART2 card

Figure 20: Using the ART2 card in a more advanced artery problem.

3.6 INTRODUCING A LOOP.

This section is concerned with the group 4 cards of figure 11. These cards are used in the loop problem deck to indicate that the problem is a loop and to give general information about the loop. The group consists of the three cards, SETUPL, LOOP1 and LOOP2, which appear after the START card, or MPCODE card if present, in that order. The LOOP2 card may be omitted in certain circumstances explained below.

An example of the use of the cards in this section is given in the 'Example' subsection below.

3.6.1 Indicating the number of intersections in the loop (SETUPL -- cols. 19-20).

The number of intersections in the loop is entered in columns 19-20 of the SETUPL card. This number should count the intersections at the artery meetings only once, and be in the range 3-20.

3.6.2 Naming the loop (SETUPL -- cols. 65-80).

A 16 character indentifier for the loop may be placed in columns 65-80 of the SETUPL card. This field may be left blank if desired.

3.6.3 Cycle time limits (LOOP1 -- cols. 11-15 and 16-20).

MAXBAND finds one cycle time for all the intersections in the loop. The lower and upper limits must be entered in columns 11-15 and 16-20, respectively, of the LOOP1 card. These values should be in seconds and must be greater than zero. The lower limit should be less than or equal to the upper limit. The user may indicate that MAXBAND find a solution with a certain cycle length by setting both the lower and upper limits to this length. Note that in the loop problem, any cycle time limits entered on the SETUP1, SETUP2 or SETUP3 cards are ignored.

Important: In MAXBAND, minimum green times are entered in fractions of a cycle. *Care must be taken in selecting a lower cycle limit that it is great enough to provide the minimum green times desired in seconds*. If splits at an intersection are computed from volume and capacity information, but no MINGREEN card is entered, MAXBAND will use default minimum green times of 0.05 cycles.

3.6.4 Loop geometry (LOOP1 -- cols. 26-30 to 51-55).

Figure 21 shows three arteries which intersect in a loop pattern. The geometry of the loop is entered as follows:

1. Each artery is given a number 1, 2 or 3.

2. The intersections of each artery are numbered from 1 to n, where n is the number of intersections in the particular artery, according to the order in which the intersections are entered.

3. The artery meetings are entered on the LOOP1 card by giving the intersection numbers from 2. at each meeting:

   a) At the meeting of arteries 1 and 2 (A in figure 21):

      columns 26-30 contain the intersection number in artery 1, and
      columns 31-35 contain the intersection number in artery 2

   b) At the meeting of arteries 1 and 3 (B in figure 21):

      columns 36-40 contain the intersection number in artery 1, and
      columns 41-45 contain the intersection nubmer in artery 3

   c) At the meeting of arteries 2 and 3 (C in figure 21):

      columns 46-50 contain the intersection number is artery 2
      columns 51-55 contain the intersection number in artery 3

Figure 22 shows how the geometry of the loop in figure 21 is entered on the LOOP1 card. Cycle time limits of 60 and 100 seconds have also been included in columns 16-25.

3.6.5 Relating the bandwidths of the three arteries (LOOP2 -- cols. 11-15, 16-20 and 21-25). **

MAXBAND allows the user to set limits on the ratios of the outbound bandwidths of any two of the loop arteries. These are expressed as the following equations where b(1), b(3) and b(5) are the outbound bandwidths for arteries 1, 2 and 3, and k(4), k(5) and k(6) are target bandwidth ratios.

$$\begin{array}{lll} b(3) \le k(4)b(1) & \text{if } k(4) > 1 \\ b(3) \ge k(4)b(1) & \text{if } k(4) < 1 \\ b(3) = \quad b(1) & \text{if } k(4) = 1 \end{array}$$

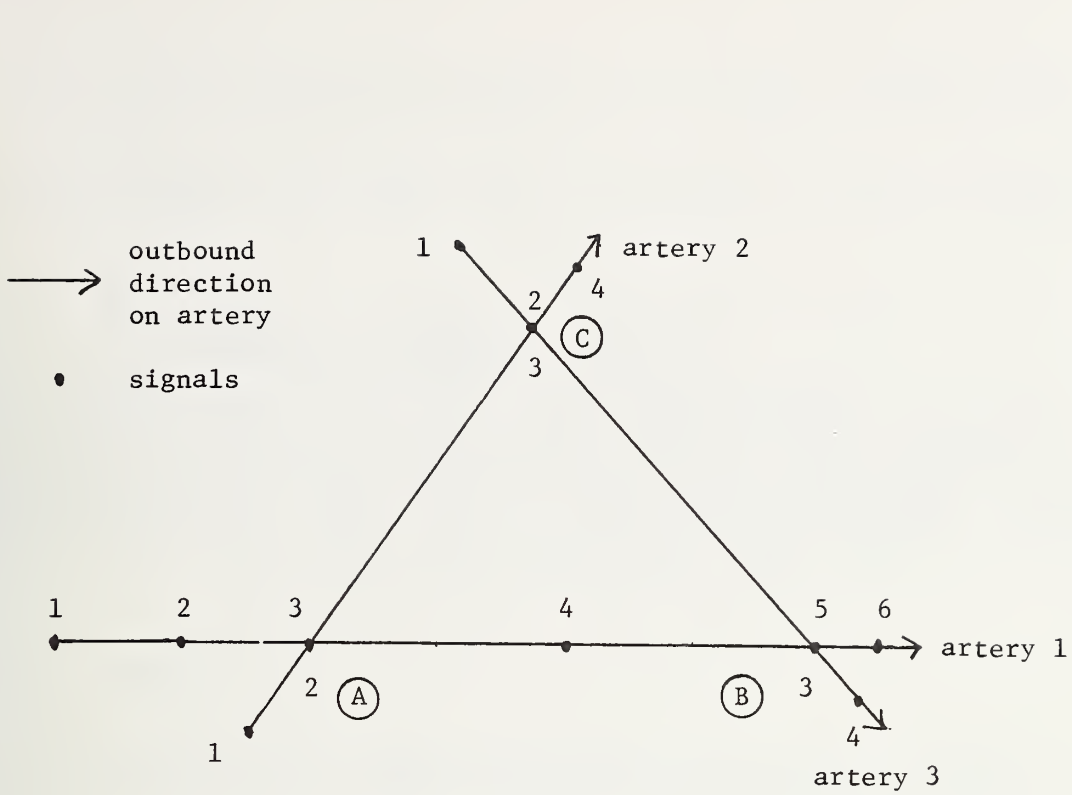


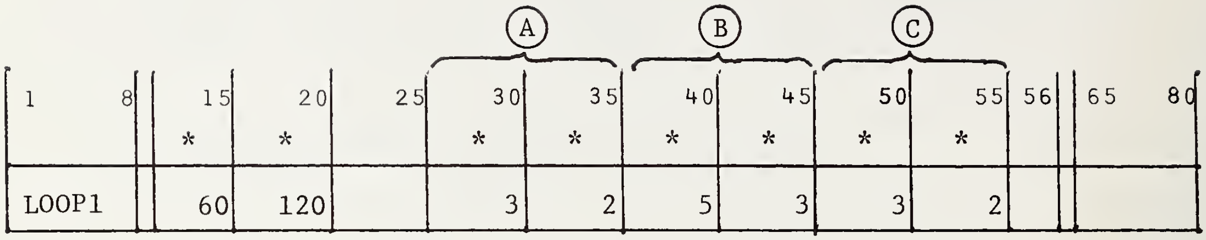
Figure 21: A sample loop.

$$\begin{array}{lll} b(5) \le k(5)b(1) & \text{if } k(5) > 1 \\ b(5) \ge k(5)b(1) & \text{if } k(5) < 1 \\ b(5) = b(1) & \text{if } k(5) = 1 \end{array}$$

$$\begin{array}{lll} b(5) \le k(6)b(3) & \text{if } k(6) > 1 \\ b(5) \ge k(6)b(3) & \text{if } k(6) < 1 \\ b(5) = b(3) & \text{if } k(6) = 1 \end{array}$$

The values of k(4), k(5) and k(6) are controlled by columns 11-15, 16-20 and 21-15, respectively, of the LOOP2 card. The values may be specified in three ways:

1. The field is left blank, The corresponding k then defaults to zero, and the bandwidth ratio equation is not set up.
2. A zero or positive value is entered in the field. This becomes the value of the corresponding k.



* indicates fields used on the LOOP1 card

Figure 22: Sample loop geometry entered on the LOOP1 card.

3. A -1 is entered in the field. The corresponding k is then computed from volume information using the formulas

$$k(4) = \begin{cases} \dfrac{\text{AOVOL}(2) + \text{AIVOL}(2)}{\text{AOVOL}(1) + \text{AIVOL}(1)} & \\ \quad \text{if } \text{AOVOL}(1) + \text{AIVOL}(1) > 0 & \\ 0 \quad \text{if } \text{AOVOL}(1) + \text{AIVOL}(1) = 0 & \end{cases}$$

$$k(5) = \begin{cases} \dfrac{\text{AOVOL}(3) + \text{AIVOL}(3)}{\text{AOVOL}(1) + \text{AIVOL}(1)} & \\ \quad \text{if } \text{AOVOL}(1) + \text{AIVOL}(1) > 0 & \\ 0 \quad \text{if } \text{AOVOL}(1) + \text{AIVOL}(1) = 0 & \end{cases}$$

$$k(6) = \begin{cases} \dfrac{\text{AOVOL}(3) + \text{AIVOL}(3)}{\text{AOVOL}(2) + \text{AIVOL}(2)} & \\ \quad \text{if } \text{AOVOL}(2) + \text{AIVOL}(2) > 0 & \\ 0 \quad \text{if } \text{AOVOL}(2) + \text{AIVOL}(2) = 0 & \end{cases}$$

where AOVOL(i) is the average outbound approach volume on artery i, and
AIVOL(i) is the average inbound approach volume on artery i.

Note that computing k(4), k(5) or k(6) requires that a VOLUME card be entered for every intersection used of the two arteries involved.

The user may choose to omit the entire LOOP2 card. In this case, k(4), k(5) and k(6) will default to zero.

The user may also weight the six bandwidths by using the objective function weights of the ART2 card.

3.6.6 Entering artery information.

The loop information (group 4) cards are immediately followed in the loop problem deck by a set of cards for each of the three arteries. These three sets are the same as that entered for a single artery, with the exceptions metioned in the 'Introducing an artery' section. The most notable exception is that the three sets start with SETUP1, SETUP2 and SETUP3 cards, respectively, rather than with a SETUP card.

3.6.7 Example.

Figure 23 shows how the loop information cards might be entered for the loop of figure 21. The SETUPL card indicates that the loop has 11 intersections, counting the intersections at artery meetings only once, and that the loop is identified as 'SAMPLE 2'. The LOOP1 card gives cycle time limits of 60 and 100 seconds. It also indicates that

arteries 1 and 2 meet at intersection 3 in artery 1 and intersection 2 in artery 2
arteries 1 and 3 meet at intersection 5 in artery 1 and intersection 3 in artery 3
arteries 2 and 3 meet at intersection 3 in artery 2 and intersection 2 in artery 3

The LOOP2 card sets the three target cross-artery bandwidths ratios k(4), k(5) and k(6) to zero. This means that no cross-artery bandwidth ratio equations will be set up. In this case, the LOOP2 card could have been omitted with the same effect.

1 8	15	20	25	30	35	40	45	50	55	56	65 80
	† #	* † #	#	†	†	†	†	†	†		*
SETUPL		11									Sample 2
LOOP1	60	100		3	2	5	3	3	2		
LOOP2	0	0	0								

* indicates field used on the SETUPL card
† indicates field used on the LOOP1 card
# indicates field used on the LOOP2 card

Figure 23: Introducing a loop problem.

3.7 ENTERING SPECIFIC SIGNAL AND APPROACH INFORMATION.

This section is concerned with the group 5 cards of figure 11. These cards give information about a specific signal and its approaches. For each intersection, the MAP card must be entered first, but the remaining group 5 cards may be entered in any order.

As shown in figure 24, the portion of the input deck for each intersection must contain a MAP card, a LENGTH card, and either a SPECIFY card or the pair of cards VOLUME and CAPACITY.

Figure 25 breaks the signal and approach (group 5) cards into five subgroups by function. Subroup a, the MAP card, indentifies the intersection. Subgroup b, the SPECIFY, VOLUME, CAPACITY and MINGREEN cards, contains the cards from which MAXBAND derives the splits used in the problem formulation. These cards all have the following eight fields:

columns 16-20	northbound through
columns 21-25	northbound left
columns 26-30	southbound through
columns 31-35	southbound left
columns 36-40	eastbound through
columns 41-45	eastbound left
columns 46-50	westbound through
columns 51-55	westbound left

Note that MAXBAND includes right turn traffic with through traffic.

Subgroup		Card Name		
5a		MAP †		
5b	may be	SPECIFY [VOLUME] [CAPACITY]	or	VOLUME CAPACITY
	entered	[MINGREEN]		
5c	in any	[LEFTPAT]		
5d	order	LENGTH [SPEED]		
5e		[QUEUE]		

† - must be first card entered for intersection

[ ] - optional

Figure 24: The portion of the input deck for a specific intersection.

5.a.	Identifying intersection.	MAP
5.b.	Deriving signal splits.	SPECIFY VOLUME CAPACITY MINGREEN
5.c.	Choosing left turn patterns.	LEFTPAT
5.d.	Giving approach information.	LENGTH SPEED
5.e	Allowing for queues at intersection.	QUEUE

Figure 25: The signal and approach cards.

The use of these fields is explained in the following subsections.

Subgroup c, the LEFTPAT card, is used to enter information about left turn patterns. Subgroup d, the LENGTH and SPEED cards, has information about the intersection approaches, and subgroup e, the QUEUE card, is used for entering information about queues at the intersection. The three cards of subgroups d and e, LENGTH, SPEED and QUEUE, all have the following fields:

columns 16-20	northbound
columns 26-30	southbound
columns 36-40	eastbound
columns 46-50	westbound

These fields contain approach lengths on the LENGTH CARD, design speeds on the SPEED card, and queue clearance times on the QUEUE card. In addition, the SPEED card has fields:

columns 21-25	northbound speed tolerance
columns 31-35	southbound speed tolerance
columns 41-45	eastbound speed tolerance
columns 51-55	westbound speed tolerance

With the exception of the VOLUME, CAPACITY and MINGREEN cards, MAXBAND uses only the fields of these cards which have to do with the outbound and inbound directions of the main street, as determined by the SETUP card. However, the user may enter information for all four directions on all the group 5 cards but MAP. This can be very useful when the intersection is part of a network or will be analyzed in several arteries. In these cases, one set of input cards can be made up for the intersection and used in several different arteries, or several different input decks. The only change required in each use would be in the sequence number (columns 21-25) and possibly identification field (columns 65-80) of the MAP card.

3.7.1 Identifying the intersection (MAP — cols. 16-20, 21-25 and 65-80).

The MAP card is used to identify a intersection and mark the point in the input deck at which information about its signal and approaches begins. For this reason, it must be the first of the group 5 cards entered for a intersection. The name of the cross street, or any other 16 character identifier, may be placed in columns 65-80 of the MAP card. A 5 character alphanumeric 'node number' may be entered in columns 16-20 of the MAP card. This may be used for indentification when the intersection is part of a large network, or is used in more than one artery. These two fields are printed in the output and are used only for information purposes. They are optional and may be left blank.

The 'sequence number', or 'order of entry' number of the intersection, must be entered in columns 21-25 of the MAP card. This number should be 1 for the first intersection entered in an artery, and increase by 1 for each subsequent intersection. MAXBAND generates internal numbers as the intersections are entered, beginning with 1 for the first intersection entered, and incrementing by 1 for each intersection entered. These internal numbers are compared with the numbers in columns 21-25 to insure that the proper number of intersections is entered and that intersections are entered in the correct order. It is these internal numbers, rather than the number in Columns 21-25 of the MAP card, which are referred to in columns 41-45 and 46-50 of the ARTERY card and columns 26-30 to 51-55 of the LOOP1 card.

Figure 26 shows a sample MAP card. The intersection has node number 503, cross street name 'STREET 1', and is the first intersection of the artery to be entered.

3.7.2 Entering splits.

MAXBAND splits are determined by the cards SPECIFY, VOLUME, CAPACITY and MINGREEN (group 5b). Either the SPECIFY card or the pair of cards VOLUME and CAPACITY must be entered for each intersection. The user chooses whether splits will be given or computed at the intersection by entering or omitting, respectively, the SPECIFY card.

1 8		15	20 *	25 *	30	35	40	45	50	55	56		65 80 *
MAP			503	1									Street 1

* indicates field used on the MAP card

Figure 26: Sample MAP card.

3.7.2.1 Entering previously computed splits (SPECIFY -- cols. 16-20 to 51-55).

The user may choose to have MAXBAND compute the splits or to use splits which have been computed previously. The latter is indicated by entering the previously computed splits on the SPECIFY card.

The SPECIFY card, like the other group 5b cards, has the following eight fields:

columns 16-20	northbound through
columns 21-25	northbound left
columns 26-30	southbound through
columns 31-35	southbound left
columns 36-40	eastbound through
columns 41-45	eastbound left
columns 46-50	westbound through
columns 51-55	westbound left

Note that MAXBAND includes right turn traffic with through traffic.

Using the outbound and inbound directions entered on the SETUP card, the splits should be entered in the outbound through (g(out)), outbound left (l(out)), inbound through (g(in)) and inbound left (l(in)) fields. The following points should be observed:

1. Values are entered in fractions of a cycle.

2. The four splits must all be greater than or equal to zero and less than or equal to one. In addition, at least one of g(out) and g(in) must be greater than zero.

3. If any of the four fields is left blank, the split will take the value of the split in the opposite direction. For example, g(out) defaults to g(in) and l(out) defaults to l(in). However, at least one of the g(out) and g(in) fields must not be blank. If both the l(out) and l(in) fields are blank, l(out) and l(in) default to zero.

4. As explained in the 'MAXBAND's internal split model' and 'How MAXBAND derives splits' sections of appendix D, splits used in the problem formulation must satisfy the equations

   $$\text{maximum }(g(out)+l(in),g(in)+l(out)) \leq 1$$

   and

   $$g(out) + l(in) = g(in) + l(out)$$

   If the first equation is not satisfied, the splits are rejected. If the second equation is not satisfied, the left split of the smaller sum will be increased until it is. On one-way streets, this means that the left split will automatically be made the same length as the through split (see the 'ONE-WAY STREETS' section at the end of this chapter).

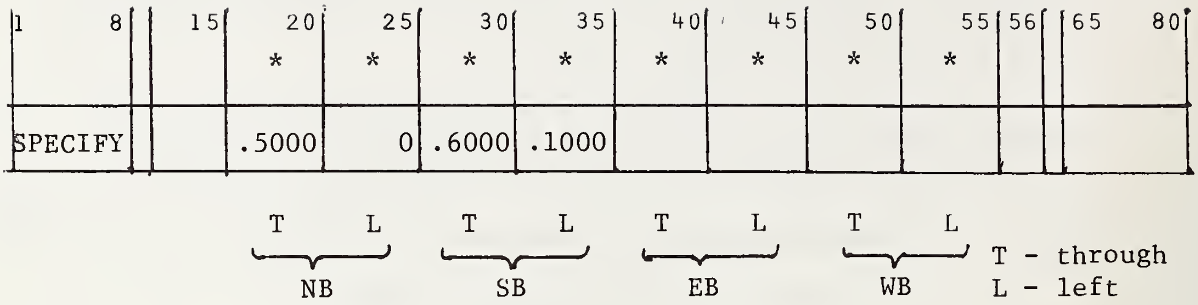
   The second equation is a result of MAXBAND's split and left turn models. The equation requires that all of the red period of the main street phase in one direction be considered, in the problem formulation, as available time for making protected left turns. However, this potential left turn time need not be used in full when the user assigns actual left turn splits. For example, if the user wishes to have both left turns lead, but begin at different times, or to have both left turns lag, but end at different times, this can be accomplished by having one of the left splits begin or end sooner or later than is indicated in the MAXBAND output.

The user may also enter splits for the cross streets. These will be ignored by MAXBAND. This feature enables the user to create intersection input cards which contain information about all four directions at a intersection. This is useful if the intersection is part of a network or appears in several arteries.

Figure 27 illustrates the use of the SPECIFY card. Assuming that the artery is entered from the south, the northbound (outbound) through split is .5, the northbound left split is 0, the southbound (inbound) through split is .6, and the southbound left split is .1. The cross street fields have been left blank.

3.7.2.2 Computing splits (VOLUME and CAPACITY -- cols. 16-20 to 51-55). **

If the SPECIFY card is not present, MAXBAND will attempt to compute splits using the method explained in the 'How MAXBAND derives splits'



1 8	15	20 *	25 *	30 *	35 *	40 *	45 *	50 *	55 *	56	65 80
SPECIFY		.5000	0	.6000	.1000						
		T	L	T	L	T	L	T	L		
		NB		SB		EB		WB			

T - through
L - left

* indicates fields used on the SPECIFY card

Figure 27: Using the SPECIFY card.

section of appendix D. This requires that the VOLUME and CAPACITY cards be present.

The VOLUME and CAPACITY cards contain the same eight fields as the SPECIFY card. On the VOLUME card, these fields contain volumes of traffic flow, through and left, on the four approaches to the intersection. On the CAPACITY card, the fields contain the maximum volumes of traffic flow, through and left, which can be handled on the four approaches to the intersection (capacities). Note that MAXBAND includes right turn traffic with through traffic. The VOLUME and CAPACITY cards differ from the SPECIFY card in that traffic volumes and link capacities for all four directions, for both through and left, must be entered. The following points should be observed:

1. Values are entered in vehicles per hour (vph).
2. MAXBAND does not handle oversaturated approaches. An error is declared if MAXBAND finds a field on a VOLUME card which contains a larger value than the corresponding field on the CAPACITY card for the same intersection.
3. The through volume and capacity for at least one direction on the main street and one direction on the cross street should be greater than zero. All the remaining volumes and capacities should be greater than or equal to zero.
4. The through volume and capacity fields for at least one direction on the main steet and one direction on the cross street should not be blank. The remaining fields can be left blank. If a field is left blank, the volume or capacity defaults to the corresponding value in the opposite direction on the same street. For example, the inbound through volume

on the main street defaults to the outbound through value on the main street. If both left fields on a particular street are blank, the left volumes or capacities default to zero on that street.

The user should note that the left volumes and capacties refer to the number of vehicles turning left from a certain direction, whether or not a left turn lane is present. Hence, values for these volumes and capacities should be entered regardless of whether a left turn lane is present.

If the user wishes to have a split set to zero (e.g., if no left turn interval is desired, or the artery is a one-way street) the corresponding field on the capacity card should be set to zero. Note that any of the four turning movements on the main street which has a positive value on the CAPACITY card will be given a positive split, even if it has a zero value on the VOLUME card. The precise value of the split depends on the values on the VOLUME, CAPACITY and MINGREEN cards.

Figure 62 of appendix D shows a sample split computation, including sample VOLUME and CAPACITY cards.

3.7.2.3 Establishing minimum times for splits (MINGREEN -- cols. 16-20 and 51-55). **

Regardless of whether splits have been given to or computed by MAXBAND, the user may specify minimums for them on the MINGREEN card. This feature can be used for specifying minimum splits on the main street, or a minimum period for the cross street phase.

The MINGREEN card has the same eight fields as the other group 5b cards, SPECIFY, VOLUME and CAPACITY. Minimum split times should be entered in all eight fields as follows:

1. Values are in fractions of a cycle. Note that, because of this, the lower cycle time limit should be chosen so that minimum green times in seconds will be satisfied.

2. All values must be greater than or equal to zero, and less than or equal to one.

3. Any field may be left blank. If a field is blank, the minimum is set to the value of the corresponding minimum in the opposite direction. For example, the northbound through minimum on the main street defaults to the southbound through minimum on the main street. If the field of the corresponding minimum is also blank, both minimums are set to zero.

4. After the defaults have been satisfied, the minimums must

satisfy the equation

$$\text{maximum } (\text{ming(NB)+minl(SB)},\text{ming(SB)+minl(NB)}) + \text{maximum } (\text{ming(EB)+minl(WB)},\text{ming(WB)+minl(EB)}) \leq 1$$

where MING(i) is the through minimum in direction i, and MINl(i) is the left minimum in direction i. This equation insures that the minimums are feasible (see the split model and split derivation sections).

5. The cross street minimums are used only to establish a minimum length for the cross street phase. MAXBAND's input section deals with only one artery at a time, and on that artery, only with main street splits. Hence, the cross street splits are not available to be modified by the cross street minimums on the MINGREEN card. This means that, in the loop problem, the user must be sure to enter the minimum split lengths he desires for a particular phase (main or cross) at one of the three artery meeting intersections, on a MINGREEN card in the portion of the deck concerned with the artery in which that phase is the main street phase.

3.7.3 Entering volume information (VOLUME -- cols. 16-20 to 51-55). **

When the user has requested, on an ARTERY or LOOP2 card, that a target bandwidth ratio (k, k(4) - k(6)) or an objective function weight (c(1) - c(6)) be calculated from volume information, MAXBAND requires that a VOLUME card be entered for every intersection being analyzed. The volume information is entered on the VOLUME card in these cases just as specified in the computing splits section above.

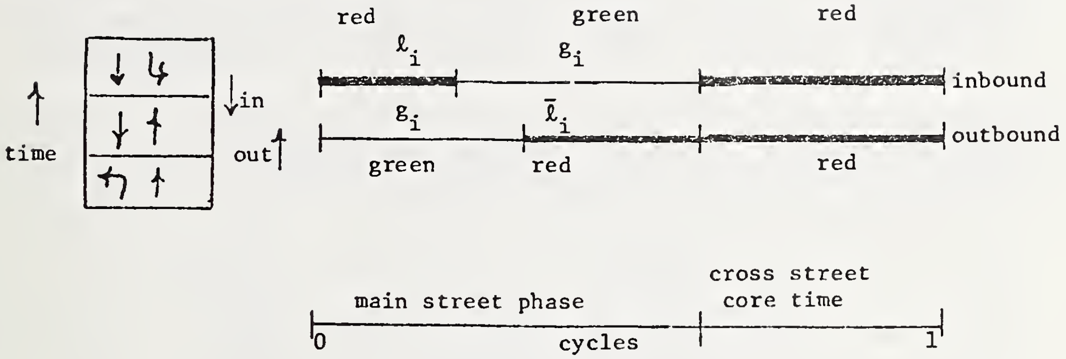
3.7.4 Choosing left turn patterns (LEFTPAT -- cols. 15,20,25 and 30). **

Figure 60 of appendix D shows the model of splits used by MAXBAND. Within each phase, left turns in one direction correspond to red times in the other direction. Since these red times may be placed at either end of the phase, four left turn patterns are possible. These patterns are shown in figure 28, which is the same as figure 13 of chapter 2.

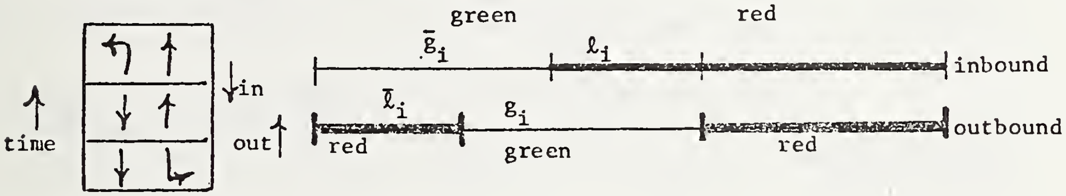
In finding an optimal solution for the arrangement of the main street splits, MAXBAND will consider only those left turn patterns which the user has chosen by inserting a 1 in the appropriate field of the LEFTPAT card. These fields are:

column 15 to choose pattern 1
column 20 to choose pattern 2
column 25 to choose pattern 3

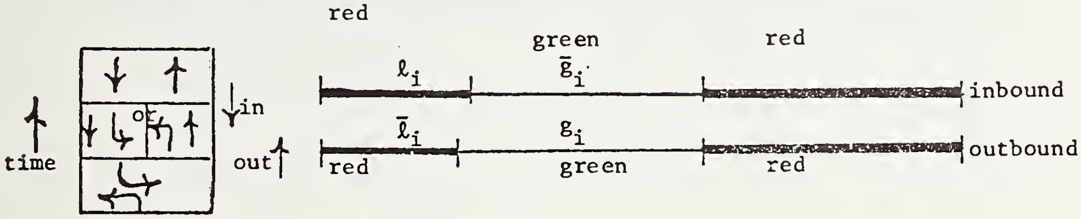
1. Outbound left leads, inbound lags



2. Outbound left lags; inbound leads



3. Outbound left leads; inbound leads



4. Outbound left lags; inbound lags

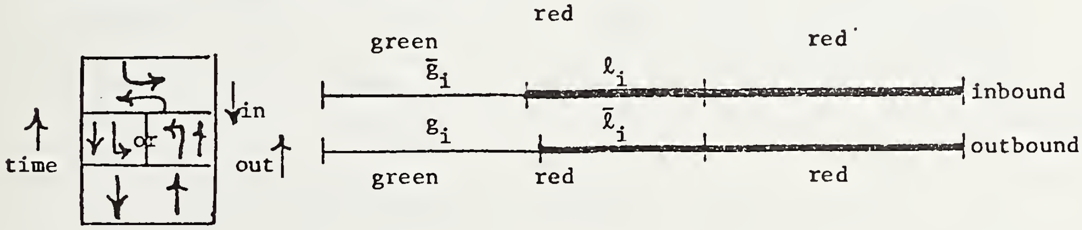


Figure 28: The four left turn patterns.

column 30 to choose pattern 4

Points to be observed:

1. The choice of a left pattern for consideration is indicated by inserting a 1 in the proper field. The patterns whose fields are blank or contain some value other than 1 are not considered.

2. If only one left split is positive at a intersection, then the four patterns of figure 28 actually represent only two possible split arrangements. For consistency, MAXBAND considers these arrangements as simplifications of patterns 1 and 2. For example, if only the outbound left green split is positive at a intersection, then pattern 3 is equivalent to pattern 1 and pattern 4 is equivalent to pattern 2. If the user in this case specifies that only pattern 3 should be considered, the MAXBAND solution report will in fact indicate that pattern 1 (identical to pattern 3 in this case) has been selected.

3. If neither of the left splits at a intersection is positive, MAXBAND will ignore the choices entered.

4. If both left splits are positive, but the LEFTPAT card is blank, has been omitted, or contains all zeroes, MAXBAND will automatically consider all four left turn patterns as it finds the optimal solution.

5. If only one left split is positive, but the LEFTPAT card is blank, has been omitted, or contains all zeroes, MAXBAND will automatically consider left turn patterns 1 and 2.

1 8	15	20	25	30	35	40	45	50	55	56	65 80
	*	*	*	*							
LEFTPAT	1	1									

* indicates fields used on the LEFTPAT card

Figure 29: Sample LEFTPAT card.

Figure 29 shows a sample LEFTPAT card. Left turn patterns 1 and 2 have been selected.

3.7.5 Giving approach lengths (LENGTH -- cols. 16-20,26-30,36-40 and 46-50).

MAXBAND requires that a LENGTH card be entered for every intersection. The lengths of the outbound and inbound approaches to the intersection should be entered in the appropriate fields of the card. These fields are:

columns 16-20 northbound approach length
columns 26-30 southbound approach length
columns 36-40 eastbound approach length
columns 46-50 westbound approach length

Points to be observed:

1. Values are entered in feet or meters, depending on the units chosen on the SETUP card.

2. Values must be greater than zero, with the exceptions noted below.

3. The length of the outbound approach must be entered, with the one exception noted below. The user may either enter the inbound approach length or leave its field blank. If the inbound approach length is not entered, it will be set to the length of the outbound approach length at the next intersection. Hence, if the lengths of the outbound and inbound links between two consecutive intersections are the same (i.e., lengths are symmetric), the user need only enter the length of the outbound link.

4. MAXBAND does not use the lengths of the outbound approach to the first intersection of the inbound approach to the last signal. The corresponding fields on the LENGTH cards for these intersections may be left blank, or a value of zero may be entered for either of the two lengths.

Figure 30 illustrates the use of the LENGTH card. The length cards for the first three intersections of an artery entered from the south are shown. Here the outbound direction is north, and the inbound direction is south. The northbound field on the first LENGTH card has been left blank because MAXBAND does not use this value (it could have been entered, if desired). The southbound field contains the length of the inbound approach. This value had to be entered because it is different from the length of the outbound approach to intersection 2. The northbound field

Signals entered from south

Inter- section	1 8		15	20 *	25	30 *	35	40 *	45	50 *	55	56		65 80
1.	LENGTH					325								
2.	LENGTH			300										
3.	LENGTH			350		400								
				NB		SB		EB		WB				

* indicates fields used on the LENGTH card

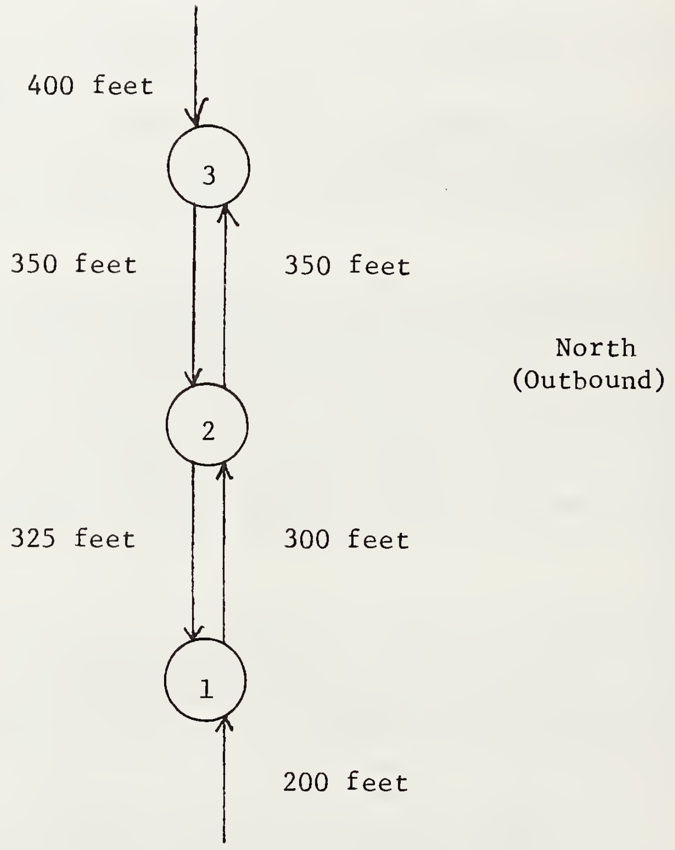


Figure 30: Using the LENGTH card.

on the second LENGTH card has the length of the outbound approach to intersection 2. The southbound field is left blank because the inbound approach to intersection 2 has the same length as the outbound approach to intersection 3, and so does not need to be entered. The third LENGTH card has the lengths of the outbound and inbound approaches to intersection 3. If the artery had only three intersections, the length of the inbound approach to intersection 3 would not have to be entered. Note that the three LENGTH cards do not appear next to each other in the deck, but each card appears in the portion of the deck giving information about its specific intersection.

3.7.6 Speeds on approaches (SPEED -- cols. 16-20 to 51-55). **

Default design speeds and design speed tolerances for an entire artery are given on the ART2 card. The SPEED card can be used to override these values on specific intersection approaches. The design speeds are entered in

columns 16-20 for the northbound approach
columns 26-30 for the southbound approach
columns 36-40 for the eastbound approach
columns 46-50 for the westbound approach

and the design speed tolerances are entered in

columns 21-25 for the northbound approach
columns 31-35 for the southbound approach
columns 41-45 for the eastbound approach
columns 51-55 for the westbound approach

Points to be observed:

1. Design speed values must be greater than zero, and design speed tolerances must be greater than or equal to zero. In addition, all the restrictions on speed values discussed in the entering artery wide speed information section (section 3.5.10) apply here.

2. The approach design speeds and design speed tolerances whose fields are left blank on the SPEED card default to the design speed and design speed tolerance entered for the appropriate direction on the ART2 card.

3. If the SPEED card is omitted, the approach design speeds and design speed tolerances default to the design speed and design speed tolerance entered for the appropriate direction on the ART2 card.

Signals entered from south

Inter-section	1 8		15	20	25	30	35	40	45	50	55	56		65 80
				*	*	*	*	*	*	*	*			
1.	SPEED			30			5							
2.	SPEED					25	7							

speed tol speed tol speed tol speed tol

NB SB EB WB

* indicates fields used on the SPEED card

Artery wide default values:

design speed - 20 mph
design speed tolerance - 2 mph

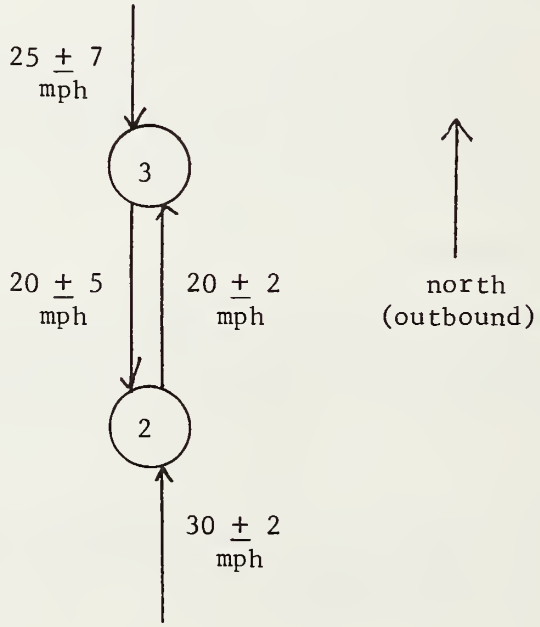


Figure 31: Using the SPEED card.

Figure 31 illustrates the use of the SPEED card. The artery wide design speed and design speed tolerance for both directions are 20 mph, and 2 mph, respectively. The artery wide design speeds have been overridden on the northbound approach to intersection 2 (to 30 mph) and the southbound approach to signal 3 (to 25 mph). The artery wide design speed tolerance has been overridden on the southbound approach to intersection 2 (to 5 mph) and on the southbound approach to intersection 3 (to 7 mph). Since the artery wide values are not overridden for the other design speeds and design speed tolerances, the coresponding fields are left blank.

3.7.7 Allowing for queue clearance times (QUEUE -- cols. 16-20,26-30,36-40 and 46-50). **

At some intersections, a queue may form during the red period which does not disappear until a considerable portion of the green period has passed. If the queue is still present during the bandwidth period, some distortion of the progression may occur. MAXBAND allows the user to deal with this problem by advancing the bandwidth period as it leaves the intersection by an amount called the 'queue clearance time'.

This effect is illustrated in figure 32. The outbound bandwidth at the second intersection has been advanced by 0.12 cycles, and the inbound bandwidth at the first intersection has been advanced by 0.16 cycles. Note the the outbound bandwidth leaving intersection 2 and the inbound bandwidth leaving intersection 1 are completely within the green period, while they are allowed to overlap the respective red periods slightly on entry. The outbound bandwidth at intersection 2 and the inbound bandwidth at signal 1 have not been advanced.

To use the bandwidth advance feature, the user enters the queue clearance times in the appropriate fields of the QUEUE card. These fields are:

columns 16-20	northbound queue clearance time
columns 26-30	southbound queue clearance time
columns 36-40	eastbound queue clearance time
columns 46-50	westbound queue clearance time

Points to be observed:

1. Values are entered in fractions of a cycle.

2. Values must be greater than or equal to zero, and less than one.

3. If a field is left blank, the queue clearance time defaults to the queue clearance time in the opposite direction. For example, the northbound queue clearance time defaults to the southbound queue clearance time. If both main street fields are left blank, the queue clearance times default to zero.

Signals entered from south

Inter-section	1 8		15	20 *	25	30 *	35	40 *	45	50 *	55	56		65 80
1.	QUEUE					.16								
2.	QUEUE			.12										
				NB		SB		EB		WB				

* indicates fields used on the QUEUE card

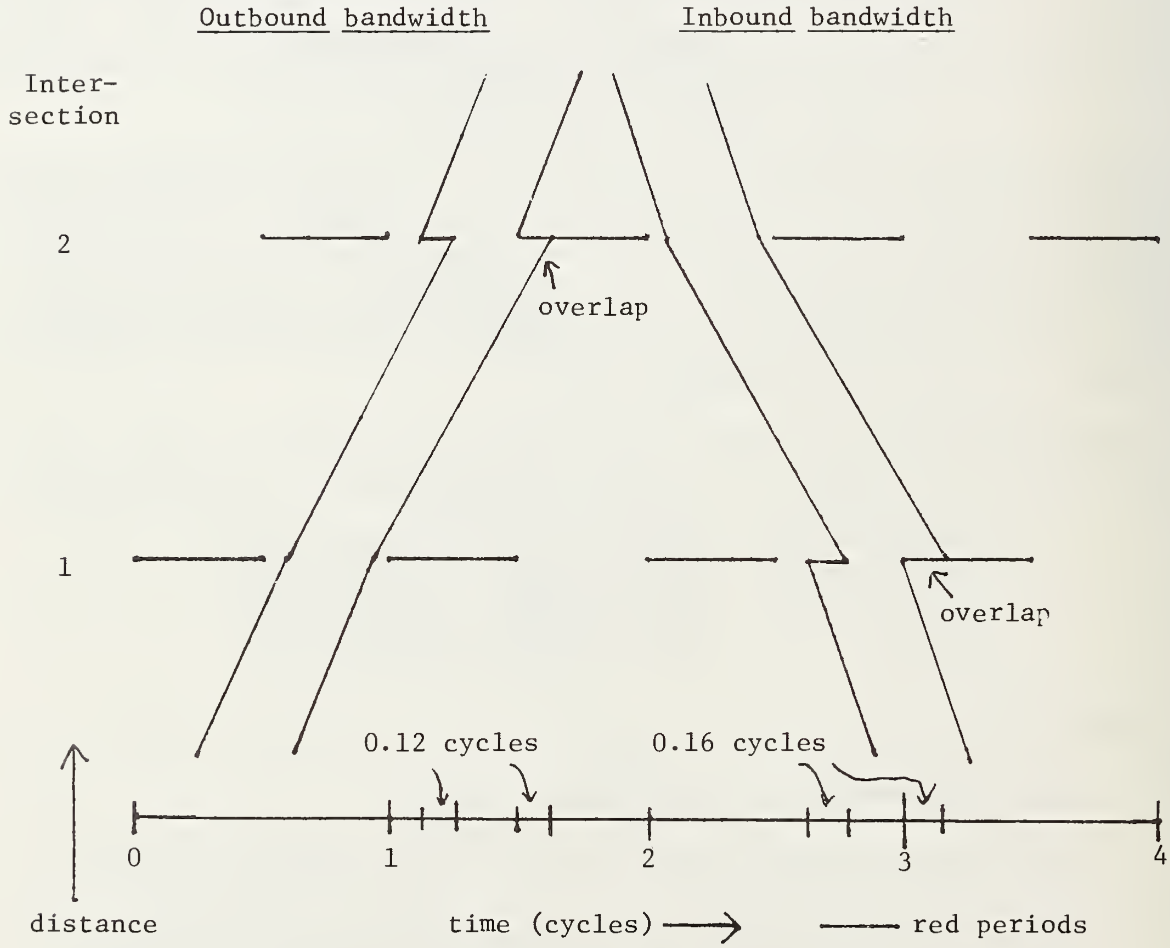


Figure 32: Using the QUEUE card.

3.8 ENDING THE JOB (END).

All decks must end with the END card.

1 8		15	20	25	30	35	40	45	50	55	56		65 80
END													

no fields are used on the END card

Figure 33: Sample END card.

The END card is illustrated in figure 33. Except for the name, the card is entirely blank.

3.9 ENTERING COMMENTS (COMM -- COLS. 9-80).

Comments may be placed throughout the input deck by entering them in columns 9-80 of the COMM card. These comments will appear in the input card section of the MAXBAND output, just as they appear in the input deck. Figure 34 shows a sample COMM card.

1 8	9 * 80
COMM	THIS IS A SAMPLE COMMENT.

* indicates fields used on the COMM card

Figure 34: Sample COMM card.

3.10 RESTARTING. **

MAXBAND uses the maximization routine MPCODE to optimize its problem formulations. As explained in the the 'SETTING OPERATING PARAMETERS FOR MPCODE' section, there is a limit (MAXRBB) on the total number of steps, or iterations, which MPCODE is allowed to use to solve a problem. The number of iterations required by the maximization routine can increase very rapidly with the size of a problem (in number of intersections). Hence it is not always clear what a proper upper limit should be. However, since the cost of solving a problem is closely related to the number of iterations its solution requires, it is desirable to have some upper limit.

MPCODE resolves this problem by allowing problems to be restarted at the point where they are halted. This means that MAXRBB does not have to excessively large. If MAXRBB is about to be exceeded, MAXBAND writes the current internal state of MPCODE to an output file, with FORTRAN file number seven, and prints the message

```
THE BRANCH AND BOUND ROUTINE HAS  EXCEEDED THE ALLOWED NUMBER OF
ITERATIONS.  CHECK THE VALUE OF MAXRBB
```

in the output. The problem can be restarted by

1. Changing the job control language so that the restart file written on unit seven is input on unit eight, and a new output file is attached to unit seven (in case the problem has to be restarted again).

2. Entering a 1 in column 40 of the MPCODE card.

3. Running MAXBAND with this new job control language and with the new MPCODE card inserted in the original problem deck, which is otherwise unchanged.

When restarting, the user may wish to change the other values on the MPCODE card (see the 'SETTING OPERATING PARAMETERS FOR MPCODE' section) to insure that the job completes without interruption.

A problem may be restarted any number of times, so long as a new output file is attached to unit seven before each run.

1 8		15 *	20 *	25 *	30 *	35 *	40 *	45	50	55	56		65 80
MPCODE							1						

* indicates fields used on the MPCODE card

Figure 35: Using an MPCODE card for restarting.

Figure 35 shows an MPCODE card used for restarting a job. Since the MAXRBB, MAXIBB, MAXITR and MAXINV fields are all blank, these parameters take their default values.

3.11 ONE-WAY STREETS. **

MAXBAND can analyze one-way streets in both single artery and loop problems. These streets are treated as two-way streets in which one direction has through and left splits which are all zero.

The following points should be observed:

1. The direction with zero splits (called the closed lane) can be either outbound or inbound. In the loop problem, however, it is strongly recommended that the open direction on an artery be outbound to insure an optimal solution.

2. The target bandwidth ratio (k -- columns 11-15 of the ART2 card) should be set to zero on one-way streets.

3. In loop problems, the corresponding cross-artery target bandwidth ratio (k(4) - k(6) -- columns 11-15, 16-20 and 21-25 of the LOOP2 card) should be set to zero if at least one of the two arteries it relates is a one-way street whose open direction is inbound. As noted above, it is recommended in the loop problem that the open direction on an artery not be inbound.

4. The objective function weights (c(1) and c(2), or c(1) - c(6) in the loop problem -- columns 16-20 and 21-25 of the ART2 card) corresponding to the closed direction or directions should be set to zero. For example, if, in a single artery problem, the street is one-way northbound and is entered from the south, the southbound (or inbound in this case) objective function weight, c(2), should be set to zero.

5. If splits are to be given at a intersection, the through and left splits for the closed direction should be entered as zero. MAXBAND internal split model requires splits to satisfy the equation

   $$g(out) + l(in) = g(in) + l(out)$$

   where g(out),g(in),l(out), and l(in) are the outbound and inbound, through and left splits, respectively. On one-way streets, this means that the through and left splits in the open direction must have the same value. This is true even though the user may not request a specific left turn period. If no left split is entered for the open direction, the third step of the split derivation process shown in figure 61 of appendix D will automatically set the left split to the value of the through split.

6. If splits at a intersection are to be computed, zero volumes and capacities should be entered for the through and left turning movements of the closed direction on the VOLUME and CAPACITY cards. This will insure that the through and left splits computed for the closed direction are zero.

7. Since the one-way street problem is treated internally as a two-way street problem, the MAXBAND output will have information for the open and closed directions on a street. The information pertaining to the closed direction should be ignored.

Chapter 4

MAXBAND EXAMPLES.

This chapter presents four examples of MAXBAND use. The first example is a 5 intersection artery from Cambridge, Massacusetts which uses only the simplest MAXBAND features. The second is an 11 intersection artery from Waltham, Massachusetts. This example contains left turns, but does not make use of many of the other more sophisticated features of MAXBAND. The third example is a 6 intersection artery loosely based on data supplied A. M. Voorhees, and Associates, Inc. This example illustrates the computation of splits, objective function weights and the target bandwidth ratio, as well as several other advanced features. The fourth example is a three artery network (loop) from Attleboro, Massachusetts. Other than the loop feature, this example uses only the most basic features of MAXBAND.

Each example begins with diagrams showing the artery, or loop, and containing information about splits, lengths, traffic volumes, etc. Next, the data from these diagrams is shown entered into one of the standard data entry forms from Appendix C. There are different forms for basic symmetric arteries, basic assymmetric arteries, general arteries and loops. The three types of artery forms allow different levels of MAXBAND features to be used. Finally, the data from the data entry forms is shown entered into an input deck. The output produced by these decks is shown in Chapter 4: MAXBAND Output and Appendix E: Sample Outputs.

In the example discussions, numbers in parentheses refer to information in the figures showing the input cards; letters in parentheses refer to information in the figures showing the input cards and in the figures showing the input forms.

4.1 THE THREE ARTERY ENTRY LEVELS.

It was noted above that there are three data entry forms for arteries. These represent various levels of use of the MAXBAND features.

The simplest form is for the basic, symmetric artery. This artery has the properties:

1. It is symmetric. This means that every value for a particular link or intersection in the outbound direction is the same in the inbound direction.

2. Through green splits are given for each intersection. They must be the same in both directions. There are no left green splits.

3. One design speed and tolerance are used on every link in both directions. The same allowed change in speed is used in both directions.

The next level of sophistication is the basic asymmetric artery. Here the restriction of symmetry has been dropped. Hence

1. The through green splits at a intersection may be of different lengths. There may also be left green splits. The splits must satisfy the equation

   $$g(out) + l(in) = g(in) + l(out)$$

   If left green splits are present, the user should select the left turn patterns to be considered by MAXBAND.

   As explained in the 'MAXBAND'S INTERNAL SPLIT MODEL' section, this equation causes MAXBAND to include all potential protected left turn time in its formulation. However, the user need not use all of this left turn time if smaller splits are desired.

2. Design speeds and tolerances, and allowed changes in speed between links, may be different in each direction. However, only one set of values may be used in one direction.

3. Values can be assigned to the objective function weights, c(1) and c(2), and to the target bandwidth ratio, k, to emphasize the bandwidth of one direction over the other in the solution.

4. A limit can be set on the number of iterations to be performed by MPCODE.

The general artery is the most sophisticated, and may use any of the MAXBAND features. In addition to the features of the basic assymetric artery

1. Lengths, and design speeds and tolerances, may differ on each link in each direction.

2. Splits, objective function wieghts, and the target bandwidth ratio may be computed from volume and capacity information.

3. Minimum durations may be specified for splits.

4. Queue clearance times, which are used to advance the bandwidth period, may be entered for each intersection in each direction.

4.2 BASIC SYMMETRIC ARTERY: BROADWAY, CAMBRIDGE, MASSACHUSETTS.

The first example is the 5 intersection artery shown in figure 36. Splits and distance information for the artery are shown in figure 37.

Since the splits are the same in both directions, there are no left splits, the link lengths are the same in both directions and one design speed and tolerance are used throughout the artery, the artery is an example of the simplest sort of case handled by MAXBAND. Because of this, the input data has been entered on the basic artery form in figure 38.

In figure 39, this data has been entered onto MAXBAND input cards.

4.2.1 Starting the job.

The deck begins with a START card (1). Since none of the advanced features of this card are used here, it is left blank.

4.2.2 Introducing the artery.

The SETUP card (2) informs MAXBAND that the problem is an artery. It indicates that

1. The number of intersections is 5 (A);
2. The artery uses English units (B);
3. Intersections are entered from the east (C); and
4. The name of the artery is BROADWAY (D).

Intersections are entered from the east so that the outbound direction is westbound in figure 36, and the inbound direction is eastbound. This means that outbound information will be read from columns 46-55 of the signal and approach specific (group 5) cards, and inbound information from columns 36-45.

The ARTERY card (3) gives lower (E) and upper (F) cycle time limits of 60 and 120 seconds, respectively.

The ART2 card (4) indicates that the design speed for the outbound direction (G) is 25 mph. Since the fields for the tolerance (H) and the allowed change in speed between links (I) in the outbound direction have been left blank, these values default to 10% of the design speed, or 2.5 mph. Since the artery is symmetric, the three corresponding inbound speed fields have been left blank (J). Their values will default to the outbound speed values.

4.2.3 Giving Signal and Approach Information.

Following the group 3 cards are a set of signal and approach specific (group 5) cards for each intersection. Each group begins with a MAP card (5), and contains a SPECIFY card (6) and a LENGTH card (7). Each of these cards is required in this case, and the MAP card must come first. When splits are computed from volume and capacity information, the SPECIFY card is replaced by the pair of cards VOLUME and CAPACITY.

4.2.3.1 Identifying a intersection.

The MAP card (5) begins the set of group 5 cards for each intersection. It contains a sequence number (K) and the name of the cross street (L). At the first intersection, the sequence number should be 1. The name of the cross street at the first intersection is SIXTH.

4.2.3.2 Entering splits.

Since splits are given, a SPECIFY card (6) is used to enter them. Because the artery is symmetric, only a value for the outbound split is given (M). This is placed in the westbound through field, columns 46-50, of the SPECIFY card. The inbound through split will default to the same value. Since both left split fields are blank (N), the left splits default to zero.

All splits are entered in fractions of a cycle.

4.2.3.3 Entering link lengths.

Because the artery is symmetric, link lengths are entered only for the outbound direction. These are entered in columns 46-50 (O) of the LENGTH card (7). The inbound link lengths default to the outbound link lengths at the next intersection. For instance, the eastbound (inbound) approach to intersection 1 has the same length as the westbound (outbound) approach to intersection 2, in this case 1500 feet.

Distances are entered in feet or meters.

Since MAXBAND does not use the length of the outbound approach to the first intersection, this field has been left blank.

4.2.4 Ending the job.

The deck ends with the END card (8).

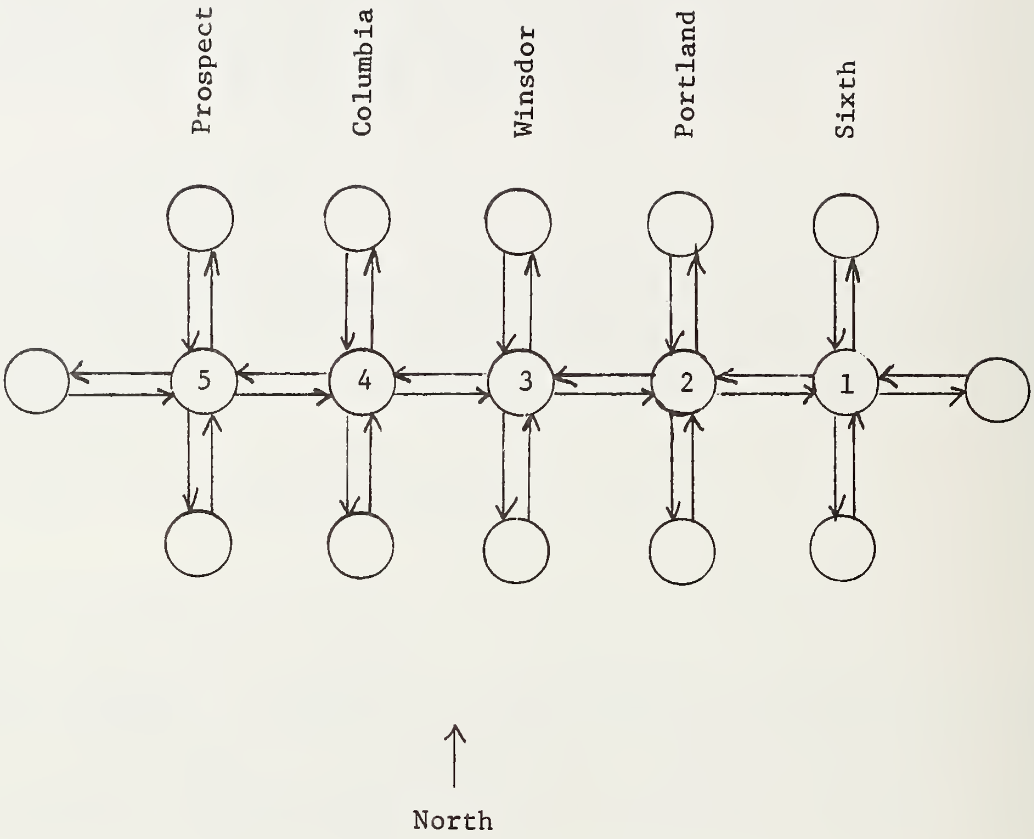


Figure 36: Broadway, Cambridge, Massachusetts

Inter-section	Cross Street Name	Distance from previous inter-section (feet)	Green times (cycles) through
1	Sixth	0	42/80
2	Portland	1500	42/80
3	Winsdor	1000	48/80
4	Columbia	550	51/80
5	Prospect	1100	32/80

Cycle time is to vary from 60 to 120 seconds. Speed is 20 ± 2 miles per hour.

Figure 37: Broadway artery data.

MAXBAND ARTERIAL INPUT

Basic Symmetric Case

Ⓓ

Name of Artery: Broadway

Number of Signals: 5 Ⓐ Units (0-English,1-metric): 0 [1]

Ⓑ

Signals entered from (N,S,E or W): E Ⓒ

Cycle time: Lower Limit: 60 Ⓔ Upper Limit: 120 Ⓕ seconds

Traffic speed (mph or kph):

Design speed: 25 Ⓖ

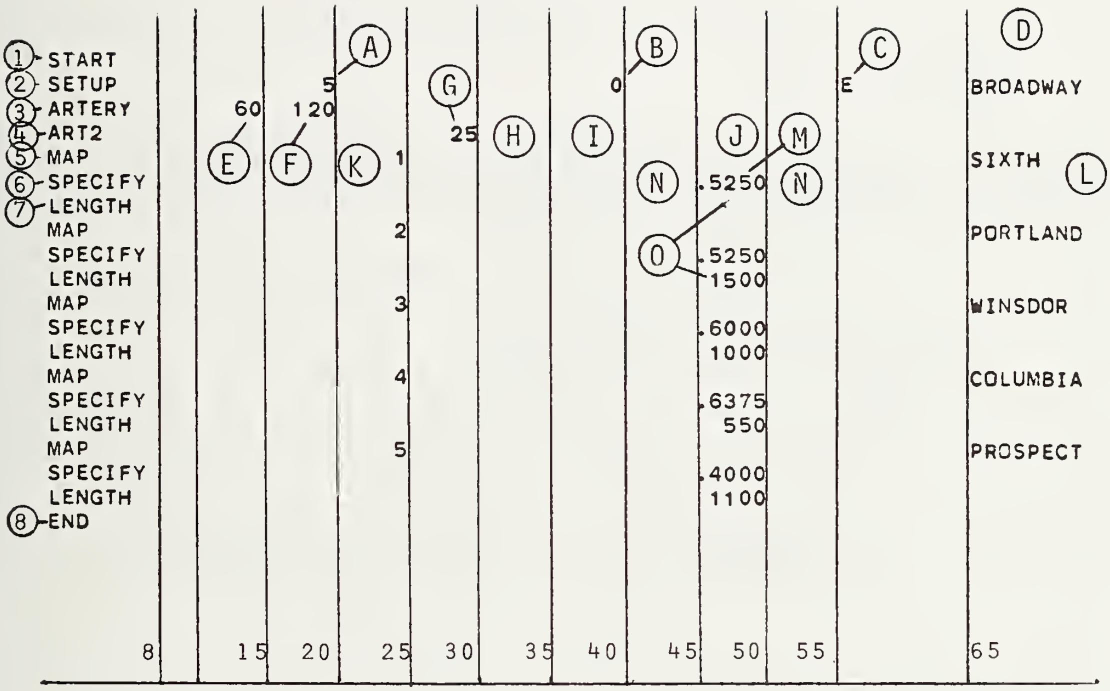
Tolerance: Ⓗ [2]

Limit on change between links: Ⓘ [3]

Inter.	Ⓛ Cross Street Name	Ⓞ Distance from previous intersection (feet or meters)	Ⓜ Main Street Green (cycles)
1.	Sixth	XXXXXXXX	.5250
2.	Portland	1500	.5250
3.	Winsdor	1000	.6000
4.	Columbia	550	.6375
5.	Prospect	1100	.4000
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

Defaults: [1] 0-English
[2] 10% of design speed
[3] speed tolerance

Figure 38: The data input form for Broadway.



```
START
SETUP                 5                0          E      BROADWAY
ARTERY          60  120
ART2                          25
MAP                      1                               SIXTH
SPECIFY                                   .5250
LENGTH
MAP                      2                               PORTLAND
SPECIFY                                   .5250
LENGTH                                     1500
MAP                      3                               WINSDOR
SPECIFY                                   .6000
LENGTH                                     1000
MAP                      4                               COLUMBIA
SPECIFY                                   .6375
LENGTH                                      550
MAP                      5                               PROSPECT
SPECIFY                                   .4000
LENGTH                                     1100
END
```

Figure 39: Broadway input cards.

4.3 BASIC ASYMMETRIC ARTERY: MAIN STREET, WALTHAM, MASSACUSETTS.

This artery consists of 11 intersections. A simplified diagram of the artery is shown in figure 40. Figure 41 contains the data which was used to enter the problem into MAXBAND. Note that some of the cross streets form t-intersections which the artery, or intersect it at an angle other than 90 degrees.

Figure 42 shows the data entered on the basic asymmetric artery form. This form was chosen because the artery has asymmetric through green splits, and left green splits, at several intersections, but contains none of the data needed to use other advanced MAXBAND features.

Figure 43 shows the input cards for this example.

4.3.1 Starting the job.

The START card is the first to appear (1). The message level (columns 11-15) and the warning level (columns 16-20) indicate that all output and all messages will be printed. Since 0 is the default values for both fields, the card could have been left blank.

4.3.2 Giving MPCODE operation parameters.

The basic asymmetric artery input form has a space for indicating the maximum number of iterations allowed the maximization routine (A). This is generally the only MPCODE parameter which the user will need to modify. However, all five MPCODE parameters, including the restart parameter, have been entered on the MPCODE card (2). Since the values chosen are the default values, the card could have been omitted.

4.3.3 Introducing the artery.

The SETUP card (3) informs MAXBAND that the problem is an artery. It indicates that

1. The number of intersections is 11 (B);

2. The artery uses English units (C);

3. Intersections are entered from the south (D); and

4. The name of the artery is WALTHAM (E).

Intersections will be entered from the south because it has been decided that the outbound direction is northbound, and the inbound direction is southbound. This choice means that outbound data will be read from columns 16-25 of the signal and approach specific (group 5) cards, and inbound data from columns 26-35.

The ARTERY card (4) gives the lower (F) and upper (G) limits for the cycle time, in seconds. It also indicates that the first intersection to be used in the analysis is 1, and the last, 11 (H). Since these are the default values, columns 41-45 and 46-50 could have been left blank.

The ART2 card (5) contains bandwidth and speed information. The target ratio of inbound to outbound bandwidth, k (I), and the outbound and inbound bandwidth objective function weights, c(1) and c(2) (J and K), have all been set to 1. This means that the equation

$$b(1) = b(2)$$

will be included in the problem formulation, and that the objective function will be

$$b(1) + b(2)$$

where b(1) and b(2) are the outbound and inbound bandwidths. Since k, c(1) and c(2) all default to 1, columns 11-25 could have been left blank.

The design speed for the links in the outbound direction (L) is 20 mph, with a tolerance (M) of 2 mph. The allowed change in speed between outbound links (N) is also 2 mph. The corresponding inbound values (O), (P) and (Q) are the same. Because of the defaults, it would have been possible to enter 20 in either columns 26-30 or 41-45, and leave the other 5 speed fields blank.

4.3.4 Giving specific signal and approach information.

The specific signal and approach information section begins with the first MAP card (6). A set of group 5 cards is included for each intersection. Each group begins with a MAP card and Includes a SPECIFY card and a LENGTH card.

4.3.4.1 Identifying the intersection.

The MAP card identifies the intersection. On the first MAP card (6), the sequence number (R) is 1 because this is the first intersection entered. The cross street name at the intersection is BANKS (S), and the node number (T) is 101.

4.3.4.2 Entering splits.

A SPECIFY card or the pair of cards VOLUME and CAPACITY must be entered for every intersection. Since splits have been given for all the intersections in this artery, the SPECIFY card (7) is always used. All splits are entered in fractions of a cycle.

The outbound direction is northbound, so the outbound throug split (U), the outbound left split (V), the inbound through split (W), and the inbound left split (X), are entered in columns 16-20, 21-25, 26-30 and 31-25, respectively. Splits could have been entered for the cross street, but they would have been ignored by the program. Note that it is necessary to enter the inbound left split, even though it is zero. This is because it would otherwise default to the value of the outbound left split.

At the second intersection, both the northbound and southbound left split fields of the SPECIFY card (10) have been left blank. These splits will both default to zero. Since the through splits are equal, it would have been possible to enter only one of them and to let the other default.

4.3.4.3 Choosing left turn patterns.

The LEFTPAT card (9) for the first intersection indicates that left turn patterns 1 and 2 (Y) will be considered. Since this is the default when only one left split is positive, the LEFTPAT card could have been left blank or omitted.

4.3.4.4 Entering link lengths.

A LENGTH card must be entered for every intersection. Since northbound is the outbound direction on this artery, the length of the outbound and inbound approaches to each intersection are entered in columns 16-20 and 26-30. However, the outbound and inbound links have the same lengths in this artery, so the inbound fields have been left blank. The length of each inbound approach will default to the length of the outbound approach at the next intersection. Because the artery uses English units, these values are entered in feet.

These points are illustrated by the first two LENGTH cards (8) and (11). The first card is completely blank. There is no outbound link length (Z) given because MAXBAND does not use this value. The inbound link (2,1) length field is blank (AA), so this length defaults to 810 feet, the length of the outbound approach to the second intersection (1,2). The second LENGTH card indicates that the outbound approach to the second intersection (1,2) (BB) is 810 feet long, and that the inbound approach (3,2) length (CC) will default to the length of the outbound approach to the third intersection (2,3).

MAXBAND does not use the length of the inbound approach to the last intersection. Hence the inbound field of the last LENGTH card (12) has been left blank.

Another way to look at the LENGTH card values is as the distance of each intersection from the previous signal in the outbound and inbound directions. Since these values are undefined at the first intersection in the outbound direction, and at the last intersection in the inbound direction, the corresponding fields may be left blank.

4.3.4.5 Other signal and link information.

No other group 5 cards are necessary here because no other advanced MAXBAND features are being used.

4.3.5 Ending the job.

An END card (13) is inserted after all the signal and link cards. Any cards after it are ignored.

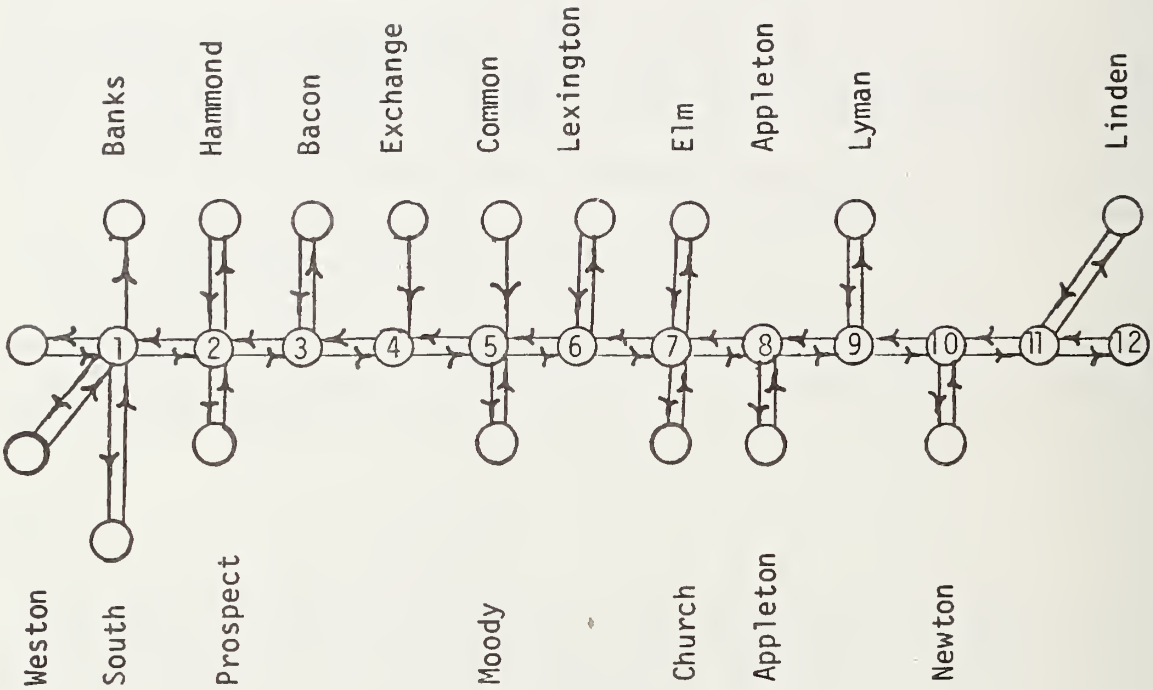


Figure 40: Main Street, Waltham, Massachusetts.

Signal	Cross Street Name	Distance from origin of artery (feet)	Green Times (cycles) outbound T	outbound L	inbound T	inbound L
1	Banks	0	55/80	12/80	43/80	0
2	Prospect	810	35/80	0	35/80	0
3	Bacon	1915	57/80	11/80	46/80	0
4	Exchange	2670	60/80	0	60/80	0
5	Moody	3470	26/80	0	26/80	0
6	Lexington	3830	53/80	22/80	31/80	0
7	Elm	4060	53/80	22/80	31/80	0
8	Appleton	4890	60/80	0	60/80	0
9	Lyman	5300	47/80	0	47/80	0
10	Newton	5640	37/80	0	37/80	0
11	Linden	6690	52/80	16/80	36/80	0

Cycle time is to vary from 60 to 100 seconds. Speed is 20 ± 2 mph.

Figure 41: Waltham artery data.

MAXBAND ARTERIAL INPUT

Basic Asymmetric Case

Name of Artery: Waltham Ⓔ Number of Signals: 11 Ⓑ
Units (0-English,1-metric) 0 [1] Ⓒ Signals entered from (N,S,E or W): S Ⓓ

Cycle times: Lower Limit: 60 Ⓕ Upper Limit: 120 Ⓖ seconds

Outbound speed (mph or kph):
Design speed: 20 Ⓛ
Tolerance: 2 Ⓜ [2]
Limit on change between links: 2 Ⓝ [3]

Inbound speed (mph or kph):
Design speed: 20 Ⓞ [4]
Tolerance: 2 Ⓟ [4]
Limit on change between links: 2 Ⓠ [4]

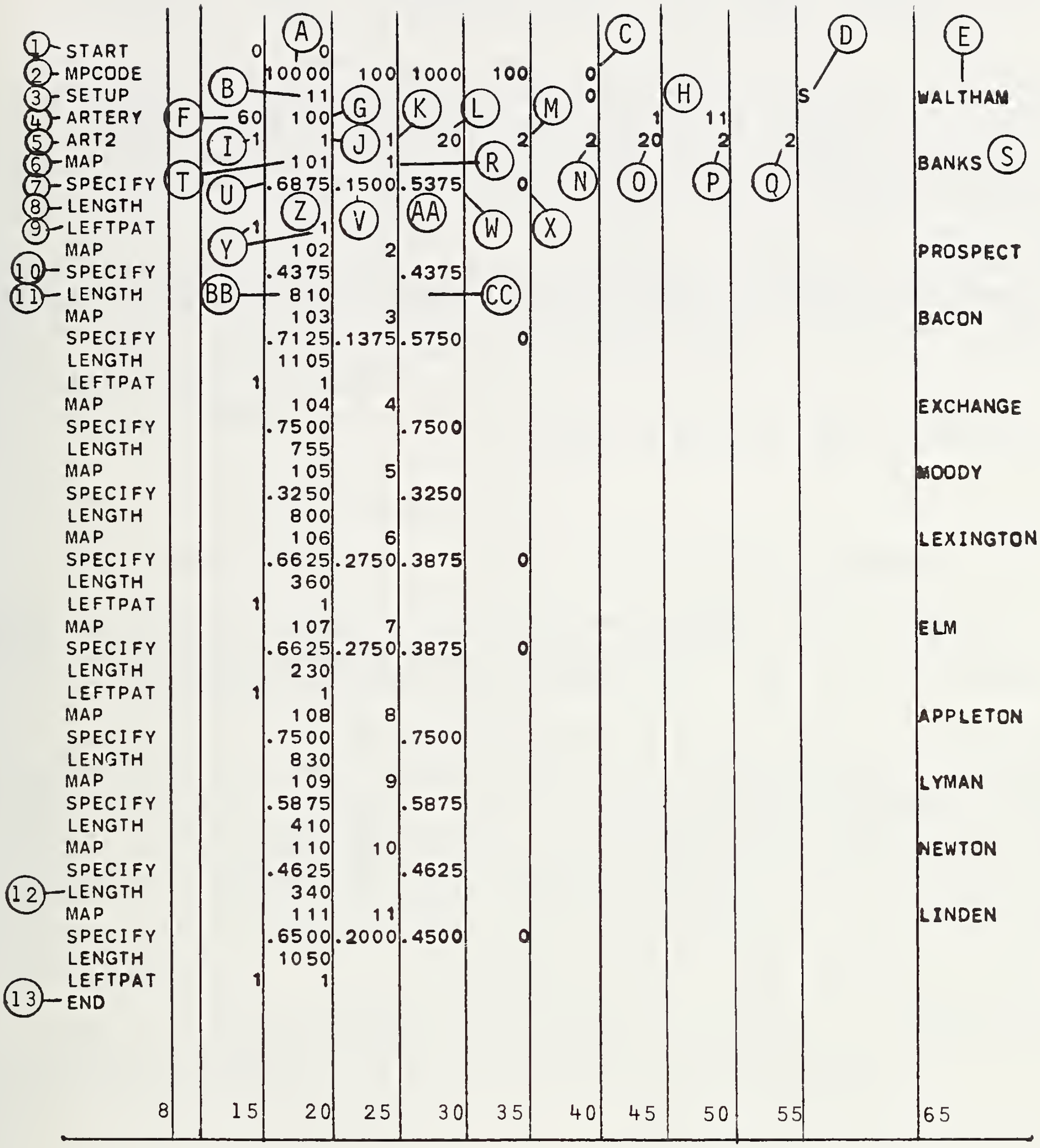
Target ratio of inbound to outbound bandwidths (k): 1 Ⓘ [5]
Objective function weights:
outbound (c(1)): 1 Ⓙ [5] inbound (c(2)): 1 Ⓚ [5]

Maximum number of MPCODE iterations (MAXRBB): 10000 Ⓐ [6]

Inter.	Cross Street Name Ⓢ	Distance from previous inter. (feet or meters) outb.	inb.	Main Street Green Times (fractions of a cycle) outbound through	outbound left	inbound through	inbound left	Left Patterns 1	2	3	4
1.	Banks Ⓩ	XXXX	(AA)	.6875	.1500	.5375	Ⓨ	x	x		
2.	Prospect	810	(CC)	.4375		.4375					
3.	Bacon	1105		.7125	.1375	.5750		x	x		
4.	Exchange	755	(BB)	.7500		.7500					
5.	Moody	800		.3250		.3250					
6.	Lexington	360		.6625	.2750	.3875		x	x		
7.	Elm	230		.6625	.2750	.3875		x	x		
8.	Appleton	830		.7500		.7500					
9.	Lyman	410		.5875		.5875					
10.	Newton	340		.4625		.4625					
11.	Linden	1050		.6500	.2000	.4500		x	x		
12.											
13.				Ⓤ	Ⓥ	Ⓦ	Ⓧ				
14.											
15.											
16.											
17.											
18.											
19.											
20.											

Defaults: [1] 0-English
[2] 10% of outbound design speed
[3] outbound speed tolerance
[4] outbound values
[5] 1
[6] 10000

Figure 42: Waltham data input form.



```
START         0    0
MPCODE         10000  100 1000  100    0
SETUP             11                   0               S    WALTHAM
ARTERY       60  100                        1   11
ART2          1    1    1   20    2    2   20    2    2
MAP              101    1                                   BANKS
SPECIFY        .6875.1500.5375    0
LENGTH
LEFTPAT       1    1
MAP              102    2                                   PROSPECT
SPECIFY        .4375     .4375
LENGTH           810
MAP              103    3                                   BACON
SPECIFY        .7125.1375.5750    0
LENGTH          1105
LEFTPAT       1    1
MAP              104    4                                   EXCHANGE
SPECIFY        .7500     .7500
LENGTH           755
MAP              105    5                                   MOODY
SPECIFY        .3250     .3250
LENGTH           800
MAP              106    6                                   LEXINGTON
SPECIFY        .6625.2750.3875    0
LENGTH           360
LEFTPAT       1    1
MAP              107    7                                   ELM
SPECIFY        .6625.2750.3875    0
LENGTH           230
LEFTPAT       1    1
MAP              108    8                                   APPLETON
SPECIFY        .7500     .7500
LENGTH           830
MAP              109    9                                   LYMAN
SPECIFY        .5875     .5875
LENGTH           410
MAP              110   10                                   NEWTON
SPECIFY        .4625     .4625
LENGTH           340
MAP              111   11                                   LINDEN
SPECIFY        .6500.2000.4500    0
LENGTH          1050
LEFTPAT       1    1
END
```

Figure 43: Waltham input cards.

4.4 A GENERAL ARTERY: THE VOORHEES EXAMPLE.

The third example is the 6 intersection artery shown in figure 44. Instead of splits, the figure shows traffic volumes and percentages of cars going straight and turning left and right at each intersection, as explained in figure 45. In figure 46, this information has been converted to traffic volumes, through and left, outbound and inbound, at each intersection.

Because splits will be computed, the general artery input form is used (figure 47). The input deck appears in figure 48. Besides split computation, the example deck demonstrates the COMM, MINGREEN, SPEED and QUEUE cards.

Only the features of this example which differ significantly from the previous two are discussed in detail.

4.4.1 Comments.

This input deck contains COMM cards (1). These may be placed anywhere in the deck. However, any cards which appear after the END card are not read and do not appear in the INPUT CARDS section of the output.

4.4.2 Starting the Job.

The START card (2) is used as in the previous example.

4.4.3 Giving MPCODE operation parameters.

The MPCODE card (3) is used has in the previous example.

4.4.4 Introducing the artery.

The SETUP (4) and ARTERY (5) cards are used as in the previous example.

The ART2 card (6) indicates that

1. The objective function weights, c(1) and c(2) (B and C), and the target bandwidth ratio, k (D), will be computed from volume and capacity information. This means that a VOLUME card has been included for each intersection included in the analysis. Here those intersections are 1 to 6, as indicated in columns 41-45 and 46-50 of the ARTERY card (A).

2. The design speeds (E) and tolerances (F), and the allowed changes in speed between links (G) are 35, 3 and 3 mph, respectively in both directions.

4.4.5 Giving specific signal and approach information.

As before, there is a set of group 5 cards, beginning with the MAP card, for each intersection. Each group must contain a LENGTH card. In the general artery case, either a SPECIFY card of the pair of cards VOLUME and CAPACITY must be present. The presence or absence of the SPECIFY card determines whether splits will be given (present) or computed (absent).

In this example, splits are to be computed at all 6 intersections, so no SPECIFY cards are used.

4.4.5.1 Identifying intersections.

The MAP card (7) is used as in the previous example.

4.4.5.2 Entering splits.

Since splits are to be computed, VOLUME (8) and CAPACITY (9) cards have been included for every intersection. These cards have traffic flows (VOLUME) and maximum traffic flows that can be handled (CAPACITY) for all four directions, through and left. For example, the northbound through volume at the first intersection (H) is 506 vph, and the eastbound left capacity (I) is 1500 vph. The capacities do not assume the presence of left turn lanes. They are simply the maximum number of vehicles per hour, going straight and turning left in each direction, that can be handled at the intersection.

Since positive capacities have been given for each of the main street turning movements at all six intersections, positive splits will be calculated for all four main street splits at all six intersections.

4.4.5.3 Entering minimum split durations.

The MINGREEN card (10) indicates that

1. The main street through splits must be at least 0.1 cycles (K);

2. The main street left splits numst be at least 0.05 cycles (L); and

3. The cross street core time (the time allocated to the cross street) must be at least 0.1 + 0.05 = 0.15 cycles (M).

Since the southbound and westbound fields have been left blank, their values default to those of the northbound and eastbound fields, respectively.

In general, if the MINGREEN card is entered, it will be used to obtain minimums for the splits in all four directions, both through and left. Leaving a field and the corresponding field for the opposite direction blank will cause both values to default to zero. This may not be the intention of the user.

4.4.5.4 Giving left turn patterns.

Because each signal will have two positive left splits, all four turning patterns will be available. The LEFTPAT card (11) indicate that all four patterns should be considered.

4.4.5.5 Entering link lengths.

The LENGTH card (12) is used as in the previous examples.

4.4.5.6 Overriding the artery-wide speed values.

The SPEED card (13) has been used at intersections 4 and 5 to override some of the artery-widespeed values. At intersection 4, the design speeds on both the outbound and inbound approaches have been changed to 32 mph (N), while the tolerances for both directions have been changed to 2 mph (O). At intersection 5, the outbound speed tolerance has been changed to 4 mph (P), and the inbound speed tolerance to 2 mph (Q).

The final values used by MAXBAND in the problem formulation appear in the LINK VALUES section of the INPUT DATA SUMMARY.

4.4.5.7 Advancing the bandwidths.

The QUEUE card (14) has been used at intersections 2 and 5 to advance the bandwidth period. The amount of the advance reflects the time required for queues at these intersections to clear after the green period begins. The advance values are added to the beginning and ending times of the bandwidth period as it enters the intersection to obtain new beginning and ending times as it leaves the intersection. The outbound bandwidth enters and leaves the intersection in the outbound direction; the inbound bandwidth enters and leaves the intersection in the inbound direction.

At intersections 2 and 5, both the outbound and inbound advances (R) have been entered as 0.05 cycles.

4.4.6 Ending the job.

The last card read from the deck is the END card (15). Since processing stops after this card, the COMM card which follows in this example is ignored.

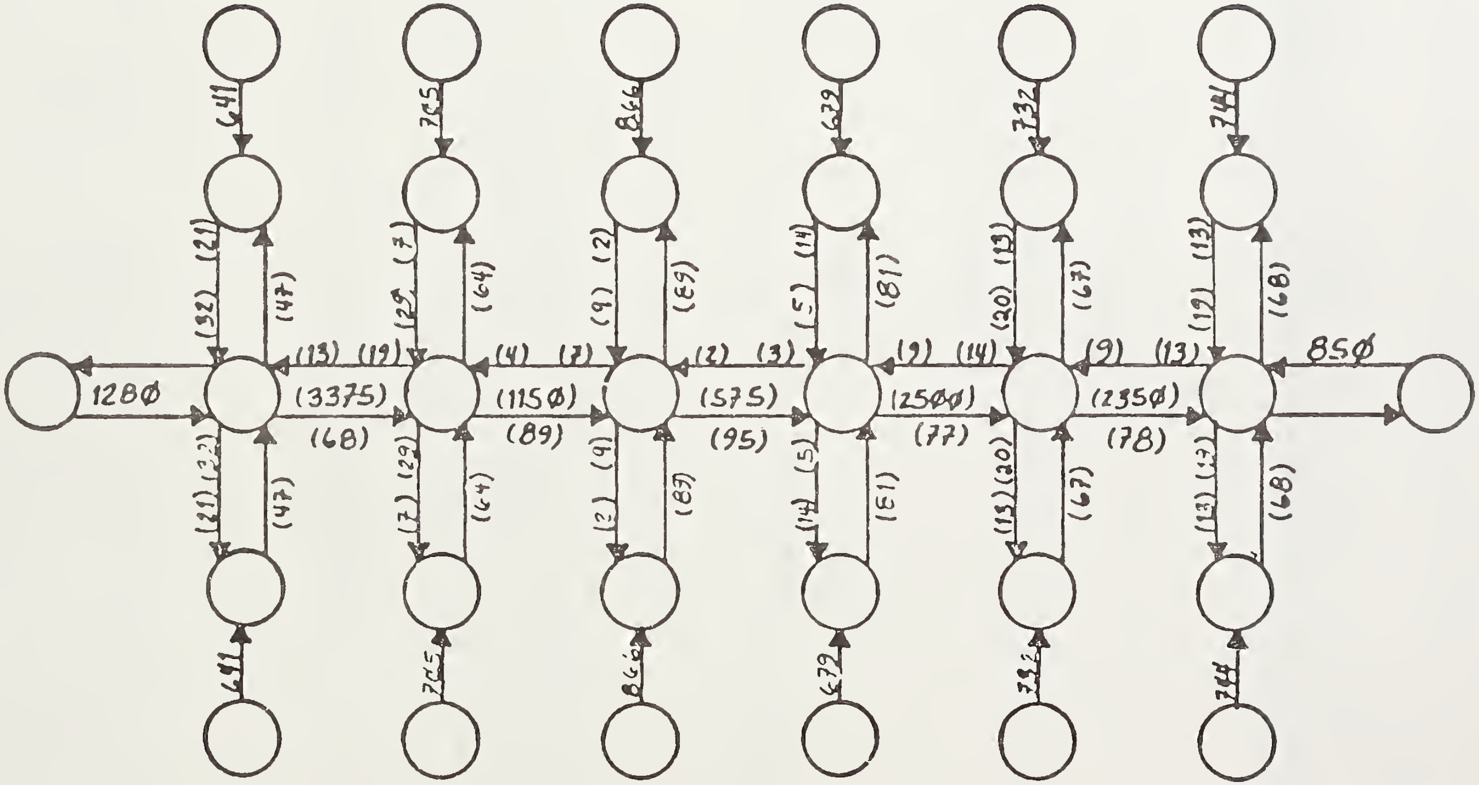


Figure 44: The Voorhees example.

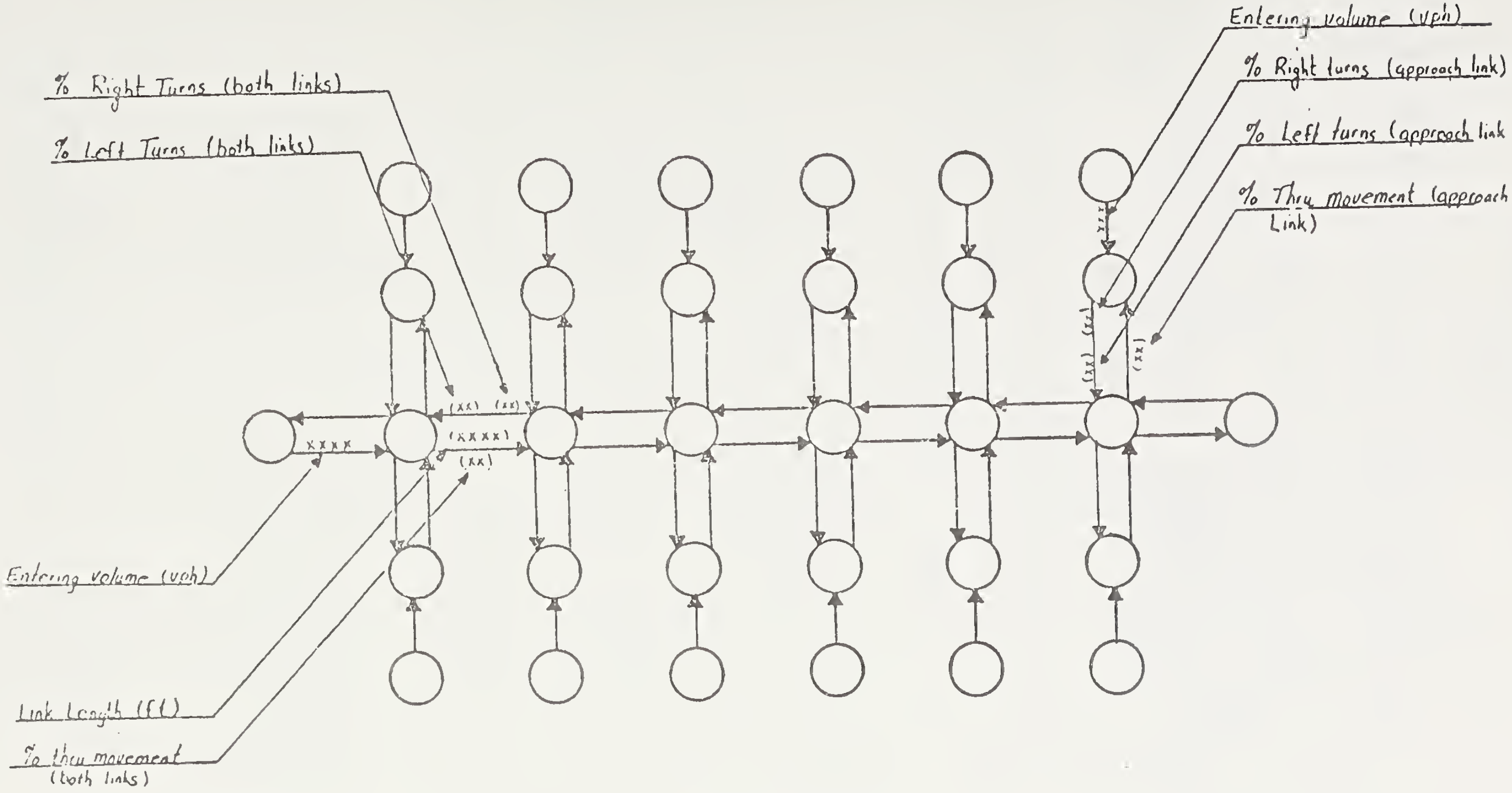

% Right Turns (both links)
% Left Turns (both links)
Entering volume (vph)
Link Length (ft)
% thru movement (both links)
Entering volume (vph)
% Right turns (approach link)
% Left turns (approach link
% Thru movement (approach Link)
xxxx
(xx)
(xx)
(xxxx)
(xx)
xxx
(xx)
(xx)
(xx)

Figure 45: Key for interpreting the Voorhees example figure.

Signal	NB Through	NB Left	SB Through	SB Left	EB Through	EB Left	WB Through	WB Left
1	506	135	436	205	1280	0	821	122
2	656	49	501	204	1471	220	912	38
3	849	17	788	78	1496	62	944	19
4	584	95	645	34	1512	31	914	90
5	637	95	586	146	1600	158	950	94
6	647	97	603	141	1499	148	850	0

Figures are in veh/hr.

Capacities are 1500 veh/hr. per lane. The roadways have 2 lanes, the left turn lanes are 1 lane.

Figure 46: The Voorhees example volume data

MAXBAND ARTERIAL INPUT

p. 1

General Case

Name of Artery: Sample
Number of Signals: 6
Units (0-English,1-metric) 0 [1]
Signals entered from (N,S,E or W): W

Cycle times: Lower Limit: 30
Upper Limit: 120 seconds

Outbound speed (mph or kph):
Design speed: 35 Ⓔ
Tolerance: 3 Ⓕ [2]
Limit on change between links: 3 Ⓖ [3]

Inbound speed (mph or kph):
Design speed: 35 Ⓔ [4]
Tolerance: 3 Ⓕ [4]
Limit on change between links: 3 Ⓖ [4]

Target ratio of inbound to outbound bandwidths (k): -1 Ⓓ [5]
Objective function weights:
outbound (c(1)): -1 Ⓑ [5]
inbound (c(2)): -1 Ⓒ [5]

Maximum number of MPCODE iterations (MAXRBB): 10000 [6]

Inter.	Cross Street Name	Distance from previous inter. (feet or meters) outb.	inb.	Main Street Green Times (fractions of a cycle) outbound through	left	inbound through	left	Left Patterns 1	2	3	4
1.	Street 1	XXXX									
2.	Street 2	3375									
3.	Street 3	1150									
4.	Street 4	575									
5.	Street 5	2500									
6.	Street 6	2350									
7.											
8.											
9.											
10.											
11.											
12.											
13.											
14.											
15.											
16.											
17.											
18.											
19.											
20.											

Defaults: [1] 0-English
[2] 10% of outbound design speed
[3] outbound speed tolerance
[4] outbound values
[5] 1
[6] 10000

Figure 47: The Voorhees example data input form

MAXBAND ARTERIAL INPUT

p. 2

General Case

Ⓗ

Traffic Volumes in vehicles per hour

Inter.	NB		SB		EB		WB	
	through	left	through	left	through	left	through	left
1.	506	135	436	205	1280	0	821	122
2.	656	49	501	204	1471	220	912	38
3.	849	17	788	78	1496	62	944	19
4.	584	95	645	34	1512	31	914	90
5.	637	95	586	146	1600	158	950	94
6.	647	97	603	141	1499	148	850	0
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								

Traffic Capacities in vehicles per hour Ⓘ

Inter.	NB		SB		EB		WB	
	through	left	through	left	through	left	through	left
1.	3000	1500	3000	1500	3000	1500	3000	1500
2.	3000	1500	3000	1500	3000	1500	3000	1500
3.	3000	1500	3000	1500	3000	1500	3000	1500
4.	3000	1500	3000	1500	3000	1500	3000	1500
5.	3000	1500	3000	1500	3000	1500	3000	1500
6.	3000	1500	3000	1500	3000	1500	3000	1500
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								

Figure 47: Continued.

MAXBAND ARTERIAL INPUT

General Case

Minimum Green Times in fractions of a cycle

Inter.	NB		SB		EB		WB	
	through	left	through	left	through	left	through	left
1.	.1000	.05			.1000	.05		
2.	.1000	.05			.1000	.05		
3.	.1000	.05			.1000	.05		
4.	.1000	.05			.1000	.05		
5.	.1000	.05			.1000	.05		
6.	.1000	.05			.1000	.05		
7.								
8.		Ⓜ			Ⓚ	Ⓛ		
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								

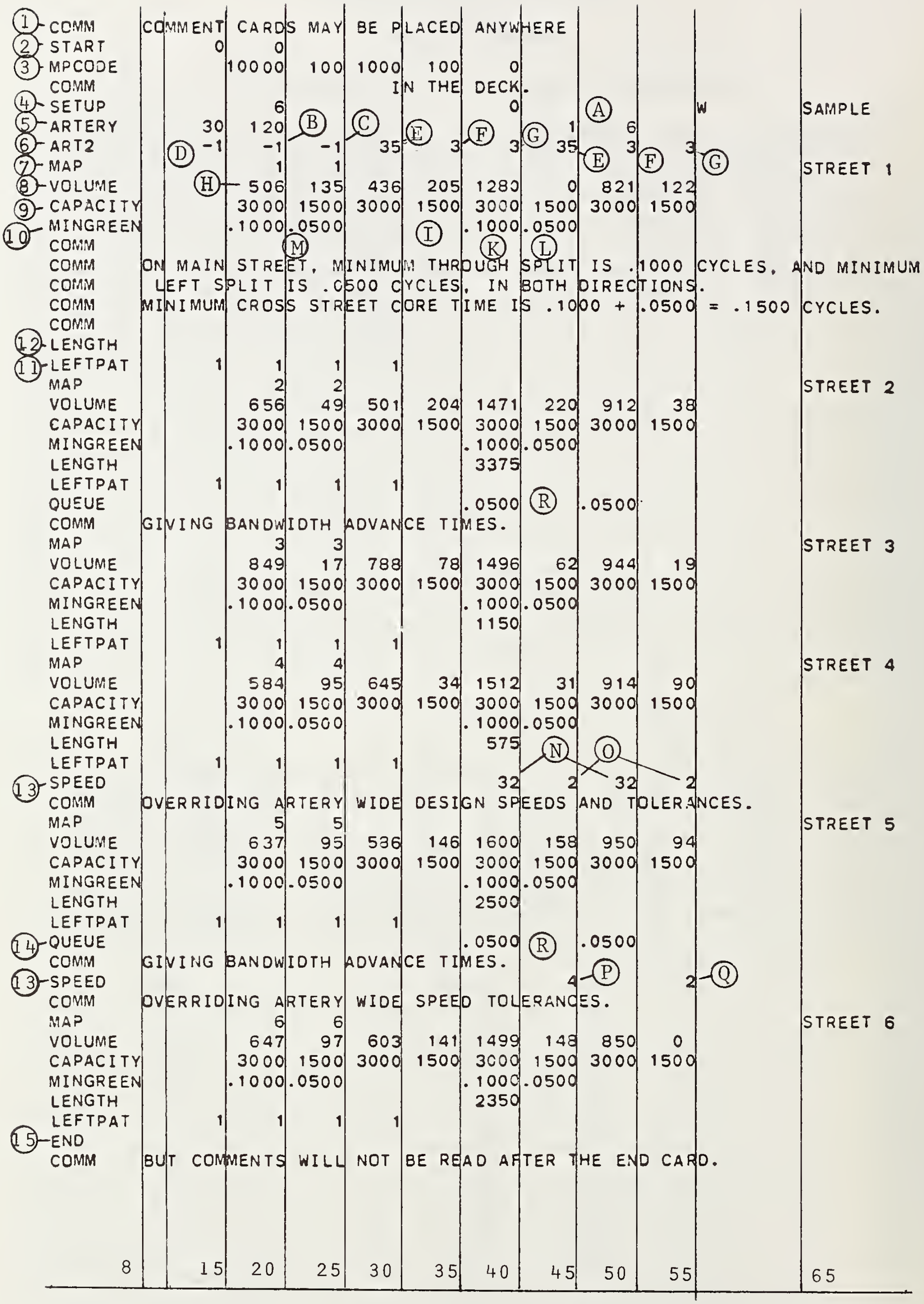
Speed values on Specific Signal Approaches (mph or kph)

Inter.	outbound		inbound	
	speed	toler.	speed	toler.
1.				
2.				
3.		Ⓝ	Ⓞ	
4.	32	2	32	2
5.		4		2
6.		Ⓟ		Ⓠ
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				
16.				
17.				
18.				
19.				
20.				

Bandwidth Advance (Queue Clear times) (cycles)

Inter.	outbound	inbound
1.		
2.	.0500	.0500
3.		
4.		
5.	.0500	.0500
6.		
7.		Ⓡ
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		
16.		
17.		
18.		
19.		
20.		

Figure 47: Continued.



```
COMM    COMMENT CARDS MAY BE PLACED ANYWHERE
START         0    0
MPCODE             10000  100 1000  100    0
COMM                         IN THE DECK.
SETUP                  6                        0               W       SAMPLE
ARTERY       30  120                                1    6
ART2         -1   -1   -1   35    3    3   35    3    3
MAP                    1    1                                       STREET 1
VOLUME               506  135  436  205 1280    0  821  122
CAPACITY            3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN           .1000.0500          .1000.0500
COMM
COMM    ON MAIN STREET, MINIMUM THROUGH SPLIT IS .1000 CYCLES, AND MINIMUM
COMM     LEFT SPLIT IS .0500 CYCLES, IN BOTH DIRECTIONS.
COMM    MINIMUM CROSS STREET CORE TIME IS .1000 + .0500 = .1500 CYCLES.
COMM
LENGTH
LEFTPAT       1    1    1    1
MAP                    2    2                                       STREET 2
VOLUME               656   49  501  204 1471  220  912   38
CAPACITY            3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN           .1000.0500          .1000.0500
LENGTH                                  3375
LEFTPAT       1    1    1    1
QUEUE                                  .0500     .0500
COMM    GIVING BANDWIDTH ADVANCE TIMES.
MAP                    3    3                                       STREET 3
VOLUME               849   17  788   78 1496   62  944   19
CAPACITY            3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN           .1000.0500          .1000.0500
LENGTH                                  1150
LEFTPAT       1    1    1    1
MAP                    4    4                                       STREET 4
VOLUME               584   95  645   34 1512   31  914   90
CAPACITY            3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN           .1000.0500          .1000.0500
LENGTH                                   575
LEFTPAT       1    1    1    1
SPEED                                     32    2   32    2
COMM    OVERRIDING ARTERY WIDE DESIGN SPEEDS AND TOLERANCES.
MAP                    5    5                                       STREET 5
VOLUME               637   95  536  146 1600  158  950   94
CAPACITY            3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN           .1000.0500          .1000.0500
LENGTH                                  2500
LEFTPAT       1    1    1    1
QUEUE                                  .0500     .0500
COMM    GIVING BANDWIDTH ADVANCE TIMES.
SPEED                                            4         2
COMM    OVERRIDING ARTERY WIDE SPEED TOLERANCES.
MAP                    6    6                                       STREET 6
VOLUME               647   97  603  141 1499  148  850    0
CAPACITY            3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN           .1000.0500          .1000.0500
LENGTH                                  2350
LEFTPAT       1    1    1    1
END
COMM    BUT COMMENTS WILL NOT BE READ AFTER THE END CARD.
```

Figure 48: The Voorhees example input cards.

4.5 A LOOP: ATTLEBORO, MASSACHUSETTS.

The fourth example is the 4 intersection loop shown in figure 49. Figure 50 gives splits and distance information for the loop.

In a loop problem, the general loop information is entered on the loop input form, while information for each of the three arteries is entered on one of the artery forms, just as for a single artery. However, the cycle time limit and maximum number of iterations fields are not used because their values are superceded by values entered on the loop input form. The forms for this example are shown in figure 51. Since the separate arteries are all symmetric, have equal through splits given, and use one set of speed values, the basic symmetric artery input forms have been used.

The input cards for this example are shown in figure 52.

4.5.1 Starting the Job.

The START card (1) is used as in the previous examples.

4.5.2 Giving MPCODE operating parameters.

The MPCODE card (2) is used as in the previous examples.

4.5.3 Introducing the loop.

The SETUPL card (3) informs MAXBAND that the problem is a loop. It indicates that

1. The number of intersections in the loop is 4 (A); and

2. The name of the loop is ATTLEBORO (B).

The LOOP1 card (4) gives cycle time limits of 60 and 120 seconds (C) and indicates the following loop geometry (D):

Arteries 1 and 2 meet at intersection 3 in artery 1 and intersection 1 in artery 2;
Arteries 1 and 3 meet at intersection 2 in artery 1 and intersection 2 in artery 3;
Arteries 2 and 3 meet at intersection 2 in artery 2 and intersection 1 in artery 3;

where artery 1 is Washington Street (entered from west), artery 2 is Newsport Avenue (entered from north), and artery 3 is HIghland avenue (entered from south).

The numbers entered in columns 26-55 refer to MAXBAND's internal order of entry numbers, not to the sequence numbers on the MAP cards.

The LOOP2 card (5) indicates that the cross-artery target outbound bandwidth ratios, k(4), k(5) and K(6), are all 0 (E). Since this is the default, the LOOP2 card could have been left blank or omitted.

4.5.4 Entering information for the three arteries.

Following the loop introduction (group 4) cards are three sets of cards which give information about each of the three arteries. the sets begin with the SETUP1 (6), SETUP2 (7) and SETUP3 (8) cards, respectively. With the exception of the cycle time limits on the ARTERY cards (10), which are omitted, each set is just as it would be for a single artery.

Note that

1. Because of the loop geometry, it is impossible to assign map directions to the three arteries which are consistent. There is always at least one artery meeting where both streets run north-south or east-west. Remember that the main purpose for entering the map direction is to indicate which fields of the group 5 cards will be read for data, not to represent the true map direction of each artery.

2. The node numbers (F) on the MAP cards (9) refer to the nodes of figure 49.

3. The ARTERY cards (10) could have been left entirely blank, since all the intersections of each artery are used in the analysis, and artery cycle times entered on the ARTERY cards are ignored.

4. Because they are the same in both directions, the design speed and tolerance, and the allowed change in speed between links (G) could have been given for only one direction on the ART2 card (11). Since k, c(1) and c(2) are set to their default values (H), the rest of the ART2 card culd have been left blank.

5. Since splits are the same in both directions, splits could have been specified for only one direction on the SPECIFY cards (12), with the rest of these cards blank. The left splits fields on all the SPECIFY cards are blank, so all the left splits default to 0.

4.5.5 Ending the job.

The END card (13) is used as in the previous examples.

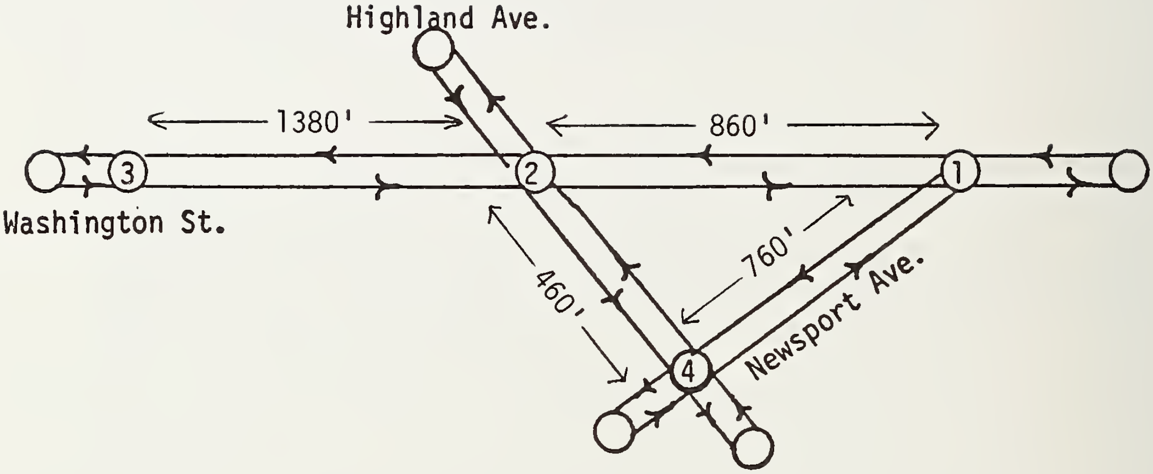


Figure 49: The Attleboro loop.

Washington Street:

Node	Cross Street Name	Distance from previous intersection (feet)	Green times (cycles) through
3	Borrows Ave.	0	.43
2	Highland Ave.	1380	.42
1	Newsport Ave.	860	.60

Newsport Avenue:

1	Washington Street	0	.25
4	Highland Avenue	760	.31

Highland Avenue:

4	Newsport Avenue	0	.54
2	Washington Street	460	.43

Cycle time is to vary from 60 to 100 seconds speed is 30 ± 5 miles per hour.

Figure 50: The Attleboro loop data.

MAXBAND LOOP INPUT

Name of loop: Attleboro Ⓑ Number of Signals: 4 Ⓐ

Cycle times: Lower Limit: 60 Upper Limit: 100 seconds

Ⓒ

Loop geometry:

Arteries 1 and 2 meet at signal 3 in artery 1
and signal 1 in artery 2

Arteries 1 and 3 meet at signal 2 in artery 1 Ⓓ
and signal 2 in artery 3

Arteries 2 and 3 meet at signal 2 in artery 2
and signal 1 in artery 3

Target ratios of outbound bandwidths:

Artery 2 to 1 (k(4)): 0 [1]
Artery 3 to 1 (k(5)): 0 [1] Ⓔ
Artery 3 to 2 (k(6)): 0 [1]

Maximum number of MPCODE iterations (MAXRBB): 10000 [2]

Information about the three arteries is entered on individual MAXBAND ARTERIAL INPUT forms.

Defaults: [1] 0
[2] 10000

Figure 51: The Attleboro data input form.

MAXBAND ARTERIAL INPUT

Basic Symmetric Case

Name of Artery: Washington St

Number of Signals: 3 Units (0-English,1-metric): 0 [1]

Signals entered from (N,S,E or W): W

Cycle time: Lower Limit: ______ Upper Limit: ______ seconds

Traffic speed (mph or kph): Ⓖ

Design speed: 30

Tolerance: 5 [2]

Limit on change between links: 5 [3]

Inter.	Cross Street Name	Distance from previous intersection (feet or meters)	Main Street Green (cycles)
1.	Borrows Ave	XXXXXXXX	.4300
2.	Highland Ave	1380	.4200
3.	Newsport Ave	860	.6000
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

Defaults:
[1] 0-English
[2] 10% of design speed
[3] speed tolerance

Figure 51: Continued.

MAXBAND ARTERIAL INPUT

Basic Symmetric Case

Name of Artery: Newsport Ave

Number of Signals: 2 Units (0-English,1-metric): 0 [1]

Signals entered from (N,S,E or W): N

Cycle time: Lower Limit: ________ Upper Limit: ________ seconds

Traffic speed (mph or kph): Ⓖ

Design speed: 30

Tolerance: 5 [2]

Limit on change between links: 5 [3]

Inter.	Cross Street Name	Distance from previous intersection (feet or meters)	Main Street Green (cycles)
1.	Washington St	XXXXXXXX	.2500
2.	Highland Ave	760	.3100
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

Defaults:
[1] 0-English
[2] 10% of design speed
[3] speed tolerance

Figure 51: Continued.

MAXBAND ARTERIAL INPUT

Basic Symmetric Case

Name of Artery: Highland Ave

Number of Signals: 2 Units (0-English,1-metric): 0 [1]

Signals entered from (N,S,E or W): S

Cycle time: Lower Limit: ______ Upper Limit: ______ seconds

Traffic speed (mph or kph): Ⓖ

Design speed: 30

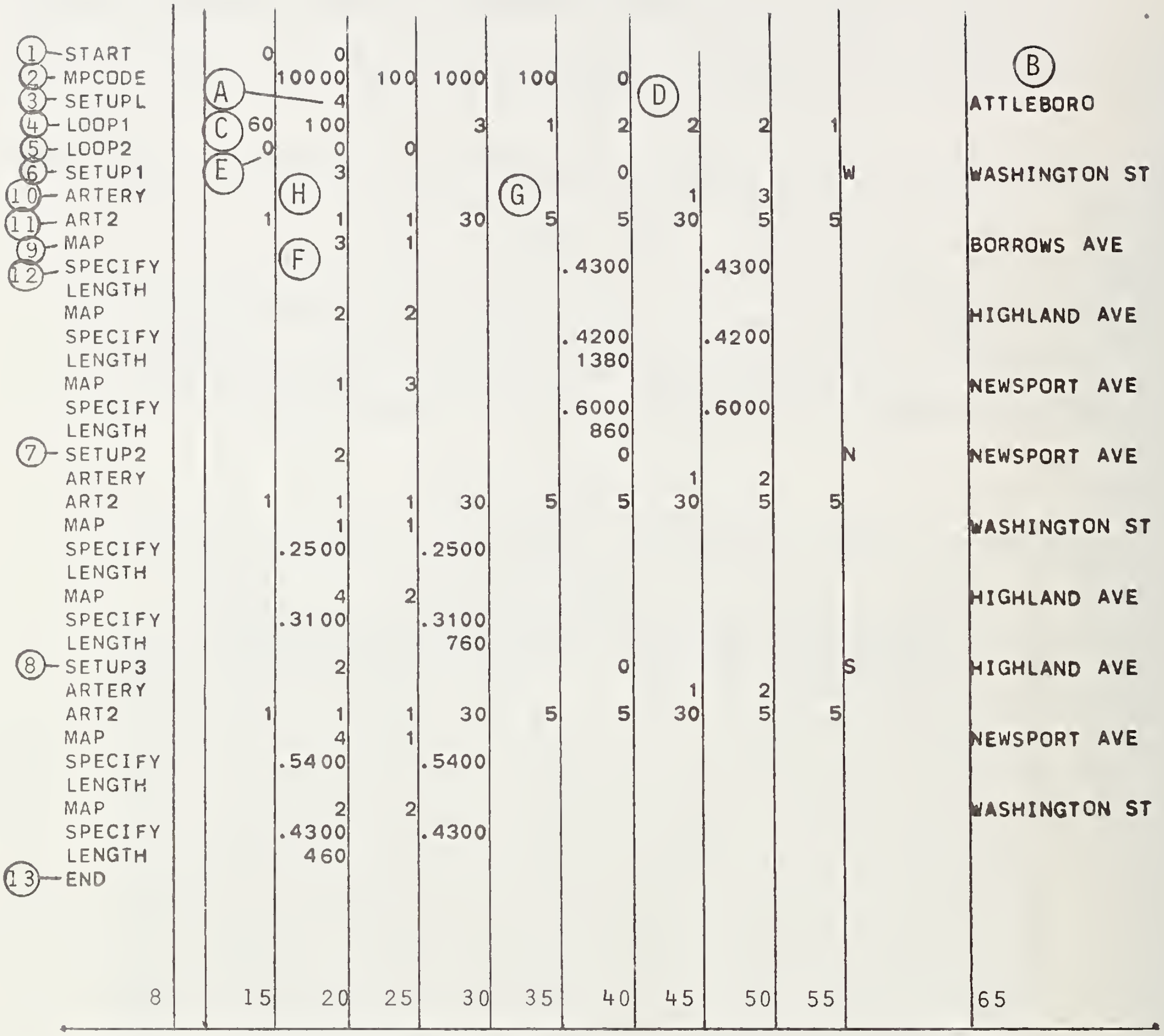
Tolerance: 5 [2]

Limit on change between links: 5 [3]

Inter.	Cross Street Name	Distance from previous intersection (feet or meters)	Main Street Green (cycles)
1.	Newsport Ave	XXXXXXXX	.5400
2.	Washington St	460	.4300
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

Defaults: [1] 0-English
[2] 10% of design speed
[3] speed tolerance

Figure 51: Continued.



```
START         0    0
MPCODE         10000  100 1000  100    0
SETUPL             4                                            ATTLEBORO
LOOP1        60  100         3    1    2    2    2    1
LOOP2         0    0    0
SETUP1             3                   0               W        WASHINGTON ST
ARTERY                                      1    3
ART2          1    1    1   30    5    5   30    5    5
MAP                3    1                                       BORROWS AVE
SPECIFY                            .4300     .4300
LENGTH
MAP                2    2                                       HIGHLAND AVE
SPECIFY                            .4200     .4200
LENGTH                              1380
MAP                1    3                                       NEWSPORT AVE
SPECIFY                            .6000     .6000
LENGTH                               860
SETUP2             2                   0               N        NEWSPORT AVE
ARTERY                                      1    2
ART2          1    1    1   30    5    5   30    5    5
MAP                1    1                                       WASHINGTON ST
SPECIFY        .2500     .2500
LENGTH
MAP                4    2                                       HIGHLAND AVE
SPECIFY        .3100     .3100
LENGTH                     760
SETUP3             2                   0               S        HIGHLAND AVE
ARTERY                                      1    2
ART2          1    1    1   30    5    5   30    5    5
MAP                4    1                                       NEWSPORT AVE
SPECIFY        .5400     .5400
LENGTH
MAP                2    2                                       WASHINGTON ST
SPECIFY        .4300     .4300
LENGTH           460
END
```

Figure 52: The Attleboro input cards.

Chapter 5

MAXBAND OUTPUT.

The MAXBAND output has been designed to let the user know, as clearly as possible, what the system is doing. This chapter discusses the MAXBAND output and includes several examples.

5.1 TYPES OF OUTPUT.

MAXBAND produces up to three output sections. The first, the MAXBAND INPUT CARDS section, echoes the input cards. The second, the INPUT DATA SUMMARY section, indicates how the input data has been interpreted and what problem values are being passed to the branch and bound routine (MPCODE). These sections are produced by the INPUT module of the MAXBAND system. The third section consists of the MPCODE STATISTICS and MAXBAND SOLUTION REPORT portions of the output. The first of these gives statistics on the performance of the maximization routine; the second prints the signal setting solution which yields the most optimal bandwidths found so far. This section is produced by the OUTPUT module of the MAXBAND system.

In addition to the three main sections, the MAXBAND output includes the title and end statements; a statement indicating whether data has been entered successfully, which appears after the INPUT CARDS section; warning and error messages, which appear throughout and after the INPUT CARDS section; a statement indicating whether MPCODE has completed successfully; and a statement indicating whether a solution is available for output. The maximization routine produces its own output on FORTRAN file 12. A dummy file may be attached to unit 12 if the user does not need this output.

5.2 CONTROLLING TYPES OF OUTPUT.

The MAXBAND user can control the amount of output by using the START card. The user may also run just the INPUT module of MAXBAND by using this card.

The START card has fields for the message level and the warning level. The message level (columns 11-15) controls which of the three MAXBAND output sections will be printed. It also can be used to stop MAXBAND after the INPUT module has produced the INPUT CARDS and INPUT DATA SUMMARY sections, but before the problem has been formulated by the MATGEN module or solved by the MPCODE module. Figure 53 illustrates the effects of the message level setting.

	PRINTED? (Y-YES,N-NO)			
VALUE	INPUT CARDS	DATA SUMMARY	MPCODE STATS AND SOL. REPT.	MPCODE EXECUTES?
0	Y	Y	Y	Y
1	N	Y	Y	Y
2	N	N	Y	Y
3	Y	Y	N	N

Figure 53: Message level settings and effects.

When the message level is 0, 1 or 2, the maximization routine executes and a solution (if one is found) is printed. Setting the message level to 3 allows the user to analyze the input data without going on to solve the problem. This allows the user to see the final data MAXBAND will use in the problem formulation before he is committed to speding computer time on the solution. This can very useful if MAXBAND has been asked to compute splits or other values from volume and capacity information. It is also useful for insuring that data is error free and that the proper fields on each card have been filled in before the problem is run.

The warning level (columns 16-20) controls the printing of warning messages. As illustrated in figure 54, warning messages are printed if the warning level is zero, and are not printed if it is one.

VALUE	PRINT WARNING MESSAGES?
0	YES
1	NO

Figure 54: Warning level settings and effects.

5.3 INPUT WARNING AND ERROR MESSAGES.

MAXBAND produces two types of messages about errors or problems in the data. These appear interspersed with the input card images of the INPUT CARDS section, and between this section and the INPUT DATA SUMMARY section. They appear whenever inconsistent or erroneous data is noted. A warning message is produced if these errors are not serious, or can be remedied by some standard procedure. A warning message does not cause

MAXBAND to halt after the INPUT module has completed execution. An error message is produced by an error serious enough to prevent proper problem formulation. This causes MAXBAND to halt after the INPUT module has completed execution.

MAXBAND keeps a tally of the errors it finds which are serious enough to produce error messages. This count is printed after the INPUT CARDS section and any subsequent warning and error messages. If the count is zero, the INPUT DATA SUMMARY will be printed, and MAXBAND will attempt to solve the problem. If the count is greater than zero, MAXBAND halts and an appropriate message is printed. In this case, the INPUT DATA SUMMARY is not printed, and MAXBAND makes no attempt to solve the problem.

MAXBAND attempts to analyze all the cards in the input deck, even if warning and error messages are produced. Only a few serious errors cause MAXBAND stop its analysis prematurely. This facility enables the user to get as much use as possible out of each run. However, the user should note that errors are not independent. Some errors will cause subsequent data to appear erroneous, even if it is not.

As explained above, the printing of warning messages is controlled by the warning level field of the START card. Error messages are always printed, regardless of the value of this field. The printing of warning and error messages is independent of the value of the message level on the START card. Hence, warning messages (if the warning level is 0) and error messages will print even if the INPUT CARDS section does not (i.e., the message level is 1 or 2).

Appendix A contains a listing of the warning and error messages produced by the INPUT module of MAXBAND.

5.4 OUTPUT ERROR MESSAGES.

MAXBAND also produces error messages if the maximization routine, MPCODE, has encountered problems during execution. These messages immediately follow a statement produced by the OUTPUT module of MAXBAND which indicates whether MPCODE has completed successfully. If MPCODE has not been able to find a solution to the problem, MAXBAND halts after printing these messages.

The output error messages are listed in Appendix B.

5.5 ARTERIES AND LOOPS.

MAXBAND can analyze both single arteries and loops -- networks of three arteries in which each artery intersects the other two at distinct intersections. In both cases, the MAXBAND output has the features described above. The loop output repeats the single artery information for each of the three arteries, and adds loop information. This repetition occurs in the INPUT DATA SUMMARY and SOLUTION REPORT sections.

5.6 OUTPUT DESCRIPTIONS AND EXAMPLES.

Figures 55 and 56 illustrate the MAXBAND output for a single artery and a loop. The artery is example 1 from chapter 4, and the loop is example 4 from chapter 4. The output produced by examples 2 and 3 of chapter 4 appears in appendix E.

In the following discussion, letters in parentheses refer to information in the outputs. Card names in parentheses indicate from which input card (if any) the output information is derived.

5.6.1 The MAXBAND title line.

The output begins at (A) with the MAXBAND title line.

5.6.2 The INPUT CARDS section.

The INPUT CARDS section begins at (B). It contains the input card images, including any comment cards, starting at (C). It may also contain warning or error messages, as seen in figure 57. If the message level on the START card (C) is 1 or 2, only the START card and any COMM cards preceding it will be echoed. Figure 58 illustrates the effect of setting the message level on the START card (C) to 1, with the same input cards as in figure 57. Figure 59 illustrates the effect of setting the warning level on the START card (C) to 1.

5.6.3 Additional warning and error messages.

The INPUT CARDS section may be followed by additional warning and error messages (D). These can be seen in figures 56, 57, 58 and 59.

5.6.4 Statement of successful data entry.

Following the INPUT CARDS section and any subsequent warning and error messages, MAXBAND prints a tally of serious errors found, and states whether data entry has been successful (E). If serious errors have been detected, data entry is not successful, and the job terminates. This can been seen in figure 57. Note that the data is considered to have been entered successfully in figure 56 even though warning messages were produced.

5.6.5 The INPUT DATA SUMMARY.

If the data has been successfully entered, an INPUT DATA SUMMARY is produced. (F) indicates the beginning of this section.

5.6.5.1 The MPCODE VALUES section.

At (G) are the parameters which will control the execution of the maximization routine (MPCODE). (H) indicates whether the job is a restart. The values at (G) and (H) are taken from the MPCODE card, or from defaults.

5.6.5.2 Artery or Loop problem.

(I) indicates whether the problem is a single artery or a loop.

5.6.5.3 General artery information.

Figure 55 contains output for a single artery. (J) is the name of the artery (SETUP). (K) is the number of intersections entered. At (L) are the lower and upper bounds on the cycle time (ARTERY or LOOP1). (M) indicates the direction from which intersections are entered (SETUP). MAXBAND considers this to be the inbound direction. This direction determines which fields of the group 5 cards (SPECIFY, VOLUME, CAPACITY, MINGREEN, SPEED, QUEUE, LENGTH) are read for data. In the INPUT DATA SUMMARY and the SOLUTION REPORT sections, MAXBAND gives information for the outbound and inbound directions on the main street, with the outbound information given first. (N) indicates whether units are English or metric (SETUP). At (O) is the target ratio of the inbound to outbound bandwidths (k) (ART2). (P) has the weights of the outbound and inbound bandwidths in the objective function (c(1) and c(2)) (ART2). Since these values may be given or computed from volume information, (Q) indicates their origin. These values are considered given if the user allows them to default.

5.6.5.4 The ARTERY WIDE VALUES section.

At (R) are the artery-wide values for the outbound and inbound design speeds and tolerances (ART2). Each of these values is used on all the links in its direction, unless overridden on a specific link by a SPEED card. The final design speeds and tolerances used by MAXBAND in its formulation of the problem are given in the LINK VALUES section of the INPUT DATA SUMMARY, which begins at (CC). Also shown at (R) are the allowed changes in speed between links in the outbound and inbound directions (ART2). These values hold for the entire artery.

5.6.5.5 The INTERSECTION VALUES section.

The INTERSECTION VALUES section lists information about specific intersections (S). (T) is the internal signal number which is generated by MAXBAND as the signals are read in. This is the number referred to in columns 41-45 of the ARTERY card and columns 25-55 of the LOOP1 card. It is also the number listed under the SIGNAL NUMBER headings in the remaining portions of the output. (U) is the node number, (V) the sequence number (the user's order of entry number), and (X) the cross street name from the MAP card.

At (W) are the left turn patterns selected by the user for consideration by MAXBAND (LEFTPAT). These are the four patterns of figure 29. They are paraphrased at the bottom of the INTERSECTION VALUES section.

At (Z) are the splits which MAXBAND will use in the problem formulation (SPECIFY, VOLUME, CAPACITY). These are the result of the split derivation process shown in figure 61. (Y) indicates whether the preliminary splits used in stage 1 of the split derivation process were given on a SPECIFY card, or computed from volume and capacity information.

At (AA) are the queue clearance times used for advancing the bandwidth as it leaves a intersection (QUEUE).

(BB) lists minimum green times, through and left, on the approaches (MINGREEN). These are displayed only if a MINGREEN card was entered for the specific intersection.

5.6.5.6 The LINK VALUES section.

The LINK VALUES section (CC) has link lengths (DD) (LENGTH), and the final design speeds (EE) and tolerances (FF) used by MAXBAND in the problem formulation. These speed values include any values entered on the SPEED card which have superceded the artery-wide values entered at (R).

5.6.5.7 Volume and capacity informaton.

If any VOLUME cards have been entered, their contents are listed at (GG). Capacities are listed for intersections at which a CAPACITY card has been entered at (HH).

5.6.6 The loop INPUT DATA SUMMARY.

Figure 56 illustrates the input data summary for a loop. This section begins at (F). The MPCODE Values section (G) and (H), and the artery or loop indication statement (I) are the same as in the artery output. (J-L) is the name of the loop (SETUPL), (K-L) the number of intersections

(SETUPL), and (L-L) the loop wide limits on cycle time (LOOP1). (L-1) lists the numbers of the intersections at which each two arteries meet (LOOP1). (L-2) gives target ratios between the indicated outbound bandwidths, along with the source of the ratios. Ratios which are allowed to default are considered to be given by the user.

The remainder of the loop INPUT DATA SUMMARY is a repetition of single artery information (J) through (HH) for each of the arteries of the loop.

5.6.7 MPCODE completion statement.

If data has been successsfully entered, the problem is passed to MPCODE for solution. Following the INPUT DATA SUMMARY section, a message is written indicating whether MPCODE has successfully completed by finding an optimal solution (II). If completion was not successful, MAXBAND writes an error message explaining the problem encountered by MPCODE. These error messages are listed in Appendix B.

Even if MPCODE did not find the optimal solution, MAXBAND will print the best solution which has been found so far. (JJ) indicates whether there is any solution available.

5.6.8 The MPCODE STATISTICS section.

This section indicates how many iterations and reinversions were performed by the entire maximization routine, and by any particular linear program (KK). These values are directly comparable to those of the MPCODE VALUES section. The section also indicates how many successively better solutions to the problem MPCODE found (LL), and what the value of the objective function

$$c(1)b(1) + c(2)b(2)$$

or

$$\begin{gathered} c(1)b(1) + c(2)b(2) + c(3)b(3) \\ + \\ c(4)b(4) + c(5)b(5) + c(6)b(6) \end{gathered}$$

is at the best solution (MM).

If no solutions have been found, MAXBAND will terminate at this point.

5.6.9 The MAXBAND SOLUTION REPORT -- artery.

If MPCODE has found at least one solution, a SOLUTION REPORT is generated. Figure 55 shows this report for a single artery.

5.6.9.1 General information.

The report first repeats information (I), (J), (K), (M) and (N) from the INPUT DATA SUMMARY. At (NN), it gives the solution cycle time. This is followed by the outbound and inbound bandwidths (OO). The value of the objective function is repeated at (PP).

5.6.9.2 General intersection information.

At (QQ), information from the MAP cards is repeated. (RR) indicates which left turn pattern has been selected by MAXBAND at each intersection with non-zero left splits. If there are no non-zero left splits, this area is left blank.

5.6.9.3 The signal settings.

At (SS) are the signal settings in fractions of a cycle. These are given for the green period, left turn period, red period, and bandwidth period, for both outbound and inbound directions. The output lists the duration of each period, when it begins, and when it ends. The Beginning and ending times are relative to the beginning of the outbound green period at the first signal, which is set to zero. The settings given for the bandwidth period are its position in the cycle as it leaves the intersection in its direction (e.g., outbound in the outbound direction). These settings are advanced from the times at which the bandwidth period entered the intersection by the amount indicated as the queue clearance time (TT). The queue clearance times are the same as those in the INPUT DATA SUMMARY (AA). The use of queue clearance times is illustrated in figure 32.

The information at (SS) and (TT) is repeated at (UU) in seconds.

5.6.9.4 Progression times and speeds.

Following the signal settings are progression times and speeds. MAXBAND first repeats the link lengths (VV) of the INPUT DATA SUMMARY (DD). Next are the traversal time (WW) and progression speed (XX) for the links.

5.6.10 The MAXBAND SOLUTION REPORT -- loop.

Figure 56 shows a solution report for a loop. The report begins by repeating general loop information (I), (J-L), (K-L) and (L-1) from the INPUT DATA SUMMARY. (NN-L) gives the solution cycle time. (OO-L) has the bandwidths and (PP-L) the objective function.

The report then repeats single artery information (J) through (XX), excluding (PP), for each of the loop arteries. All signal settings are relative to the start of the outbound green period at signal 1 of artery 1, which is set to zero.

5.6.10.1 Reiteration of settings at artery meetings.

As a convenience, MAXBAND repeats the settings of the three signals where the arteries in a loop meet. At each meeting, (L-3) indicates the intersections and arteries involved. (L-4) gives the signal settings in fractions of a cycle for the first artery; (L-5) gives them for the second. If there are any all red periods (periods when both arteries have red), these are indicated at (L-6). This information is repeated in seconds at (L-7).

5.6.11 The end statement.

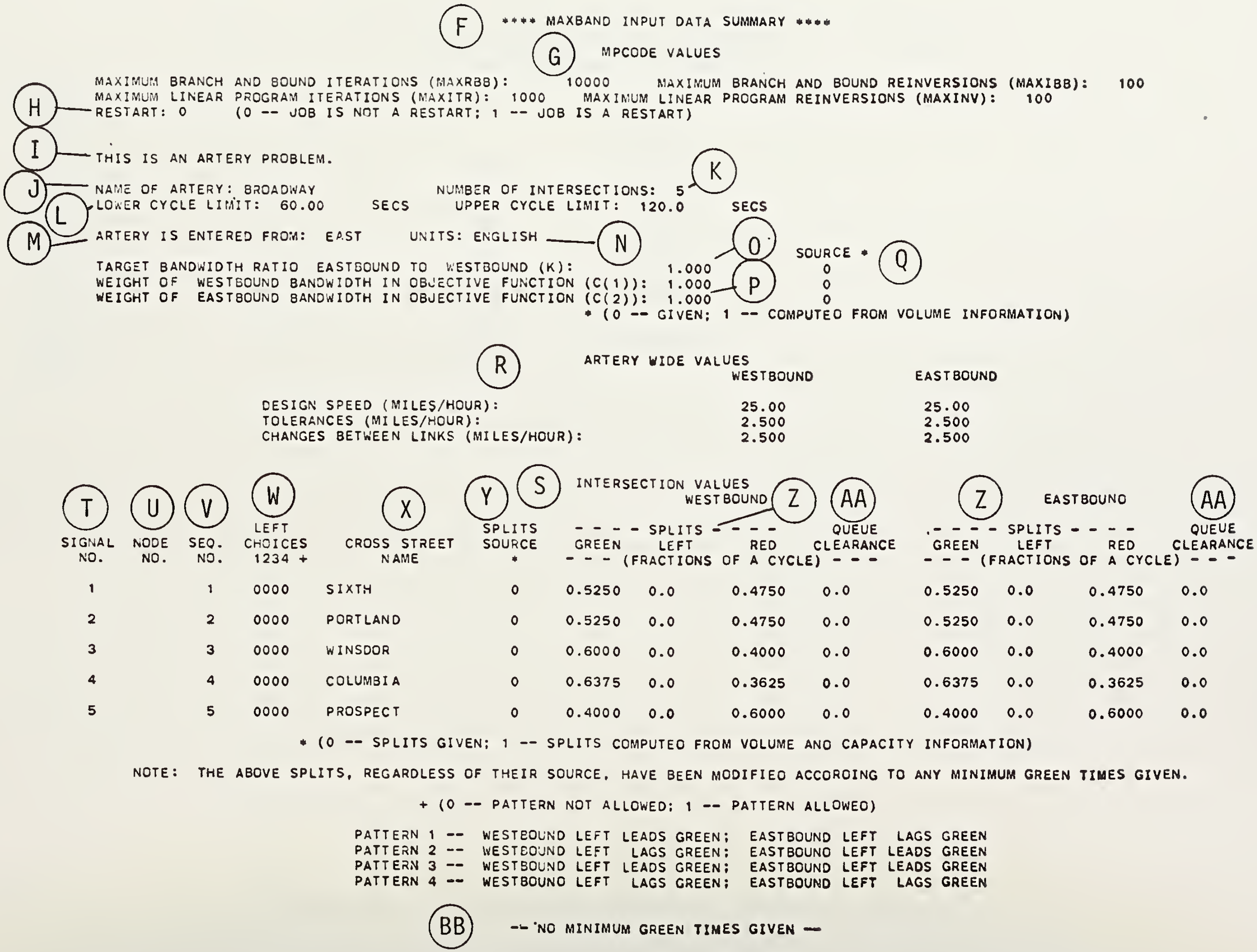
The MAXBAND END statement (YY) indicates the end of the MAXBAND job.

```
                           Ⓐ    **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****
                                                 Ⓑ    **** MAXBAND INPUT CARDS ****
Ⓒ   START
    SETUP              5                   0               E        BROADWAY
    ARTERY        60  120
    ART2                         25
    MAP                     1                                       SIXTH
    SPECIFY                                      .5250
    LENGTH
    MAP                     2                                       PORTLAND
    SPECIFY                                      .5250
    LENGTH                                        1500
    MAP                     3                                       WINSDOR
    SPECIFY                                      .6000
    LENGTH                                        1000
    MAP                     4                                       COLUMBIA
    SPECIFY                                      .6375
    LENGTH                                         550
    MAP                     5                                       PROSPECT
    SPECIFY                                      .4000
    LENGTH                                        1100
    END
```

Figure 55: Output from Broadway example of chapter 4.

```
Ⓔ . DATA HAS BEEN SUCCESSFULLY ENTERED.
```

Figure 55: Continued.



```
**** MAXBAND INPUT DATA SUMMARY ****
                    MPCODE VALUES
MAXIMUM BRANCH AND BOUND ITERATIONS (MAXRBB):      10000     MAXIMUM BRANCH AND BOUND REINVERSIONS (MAXIBB):   100
MAXIMUM LINEAR PROGRAM ITERATIONS (MAXITR):  1000    MAXIMUM LINEAR PROGRAM REINVERSIONS (MAXINV):   100
RESTART: 0     (0 -- JOB IS NOT A RESTART; 1 -- JOB IS A RESTART)

THIS IS AN ARTERY PROBLEM.

NAME OF ARTERY: BROADWAY                NUMBER OF INTERSECTIONS:  5
LOWER CYCLE LIMIT:  60.00     SECS     UPPER CYCLE LIMIT:  120.0      SECS

ARTERY IS ENTERED FROM:  EAST     UNITS: ENGLISH
                                                                          SOURCE *
TARGET BANDWIDTH RATIO  EASTBOUND TO  WESTBOUND (K):              1.000       0
WEIGHT OF  WESTBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(1)):  1.000       0
WEIGHT OF  EASTBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(2)):  1.000       0
                                                    * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

                                      ARTERY WIDE VALUES
                                                     WESTBOUND          EASTBOUND

           DESIGN SPEED (MILES/HOUR):                   25.00              25.00
           TOLERANCES (MILES/HOUR):                     2.500              2.500
           CHANGES BETWEEN LINKS (MILES/HOUR):          2.500              2.500

                                    INTERSECTION VALUES
                                              WESTBOUND                             EASTBOUND
                       LEFT                   SPLITS    - - - - SPLITS - - - -     QUEUE    .- - - - SPLITS - - - -      QUEUE
SIGNAL  NODE  SEQ.   CHOICES   CROSS STREET   SOURCE     GREEN    LEFT       RED     CLEARANCE   GREEN    LEFT      RED     CLEARANCE
 NO.    NO.   NO.    1234 +       NAME          *       - - - (FRACTIONS OF A CYCLE) - - -      - - - (FRACTIONS OF A CYCLE) - - -

  1             1     0000    SIXTH             0      0.5250   0.0      0.4750    0.0        0.5250   0.0      0.4750    0.0

  2             2     0000    PORTLAND          0      0.5250   0.0      0.4750    0.0        0.5250   0.0      0.4750    0.0

  3             3     0000    WINSDOR           0      0.6000   0.0      0.4000    0.0        0.6000   0.0      0.4000    0.0

  4             4     0000    COLUMBIA          0      0.6375   0.0      0.3625    0.0        0.6375   0.0      0.3625    0.0

  5             5     0000    PROSPECT          0      0.4000   0.0      0.6000    0.0        0.4000   0.0      0.6000    0.0

               * (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

   NOTE:  THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

                       + (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

                 PATTERN 1 --  WESTBOUND LEFT LEADS GREEN;  EASTBOUND LEFT  LAGS GREEN
                 PATTERN 2 --  WESTBOUND LEFT  LAGS GREEN;  EASTBOUND LEFT LEADS GREEN
                 PATTERN 3 --  WESTBOUND LEFT LEADS GREEN;  EASTBOUND LEFT LEADS GREEN
                 PATTERN 4 --  WESTBOUND LEFT  LAGS GREEN;  EASTBOUND LEFT  LAGS GREEN

                         -- NO MINIMUM GREEN TIMES GIVEN --
```

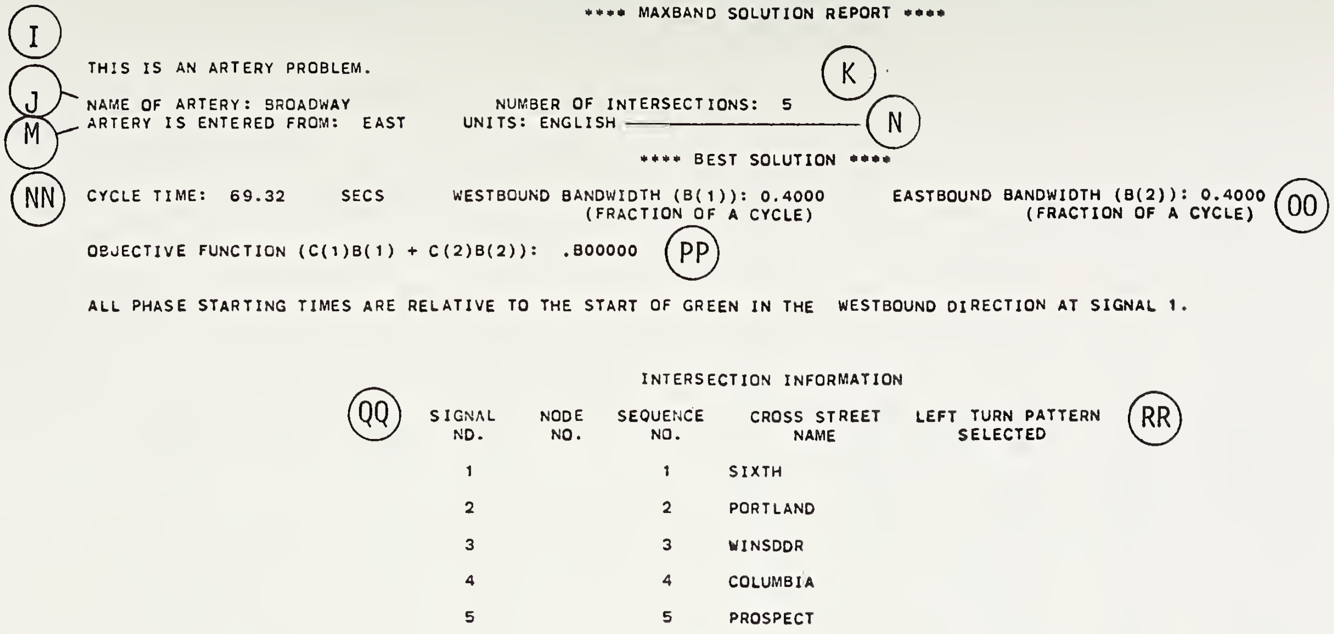
Figure 55: Continued.

```
                         EE                CC                   FF   EE
                      DD                                        DD
                                WESTBOUND         LINK VALUES             EASTBOUND          FF

  SIGNAL                LENGTH     SPEED         TOLERANCE      LENGTH.     SPEED         TOLERANCE
    NO.                 (FEET)  (MILES/HOUR)  (MILES/HOUR)      (FEET)   (MILES/HOUR)  (MILES/HOUR)

    1
          --------     1500.00     25.000        2.5000        1500.00     25.000        2.5000
    2
          --------     1000.00     25.000        2.5000        1000.00     25.000        2.5000
    3
          --------     550.000     25.000        2.5000        550.000     25.000        2.5000
    4
          --------     1100.00     25.000        2.5000        1100.00     25.000        2.5000
    5

                           GG   -- NO VOLUMES GIVEN --

                          HH   -- NO CAPACITIES GIVEN --
```

Figure 55: Continued.

```
(II)  MPCODE HAS SUCCESSFULLY COMPLETED.
       A REPORT BASED ON THE OPTIMAL SOLUTION WILL BE WRITTEN.  (JJ)

                                                  **** MPCODE STATISTICS ****

 (KK)   NUMBER OF BRANCH AND BOUND ITERATIONS PERFORMED:        36     NUMBER OF BRANCH AND BOUND REINVERSIONS PERFORMED:

        MAXIMUM NUMBER OF ITERATIONS PERFORMED BY A LINEAR PROGRAM:    27
        MAXIMUM NUMBER OF REINVERSIONS PERFORMED BY A LINEAR PROGRAM:    0

(LL) -- NUMBER OF SOLUTIONS FOUND:    1      VALUE OF OBJECTIVE FUNCTION AT LAST SOLUTION:   .800000 -- (MM)
```

Figure 55: Continued.



```
                                      **** MAXBAND SOLUTION REPORT ****

THIS IS AN ARTERY PROBLEM.

NAME OF ARTERY: BROADWAY            NUMBER OF INTERSECTIONS:  5
ARTERY IS ENTERED FROM:  EAST     UNITS: ENGLISH
                                           **** BEST SOLUTION ****

CYCLE TIME:  69.32     SECS      WESTBOUND BANDWIDTH (B(1)): 0.4000      EASTBOUND BANDWIDTH (B(2)): 0.4000
                                           (FRACTION OF A CYCLE)                    (FRACTION OF A CYCLE)

OBJECTIVE FUNCTION (C(1)B(1) + C(2)B(2)):  .800000

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE  WESTBOUND DIRECTION AT SIGNAL 1.


                                            INTERSECTION INFORMATION
                        SIGNAL     NODE   SEQUENCE    CROSS STREET   LEFT TURN PATTERN
                          NO.       NO.      NO.          NAME            SELECTED

                          1                  1        SIXTH

                          2                  2        PORTLAND

                          3                  3        WINSDDR

                          4                  4        COLUMBIA

                          5                  5        PROSPECT
```

Figure 55: Continued.

```
                                                         (SS)
                                            PHASE SETTINGS -- FRACTIONS OF A CYCLE                                  (TT)
                          - - - - GREEN - - - -    - - - - LEFT - - - -     - - - - RED - - - -     - - - - - - - BAND - - - - - - -
SIGNAL                                                                                                                    ADVANCED BY
  NO.   DIRECTION       BEGIN    END   DURATION   BEGIN    END   DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION QUEUE CLEAR
                                                                                                                             TIME

  1     WESTBOUND       .0      .5250   0.5250                    0.0      .5250   .0     0.4750    .0114   .4114  0.4000    0.0
        EASTBOUND       .0      .5250   0.5250                    0.0      .5250   .0     0.4750    .1250   .5250  0.4000    0.0

  2     WESTBOUND       .5348   .0598   0.5250                    0.0      .0598   .5348  0.4750    .5480   .9480  0.4000    0.0
        EASTBOUND       .5348   .0598   0.5250                    0.0      .0598   .5348  0.4750    .5348   .9348  0.4000    0.0

  3     WESTBOUND       .9056   .5056   0.6000                    0.0      .5056   .9056  0.4000    .9056   .3056  0.4000    0.0
        EASTBOUND       .9056   .5056   0.6000                    0.0      .5056   .9056  0.4000    .1056   .5056  0.4000    0.0

  4     WESTBOUND       .8648   .5023   0.6375                    0.0      .5023   .8648  0.3625    .1023   .5023  0.4000    0.0
        EASTBOUND       .8648   .5023   0.6375                    0.0      .5023   .8648  0.3625    .8892   .2892  0.4000    0.0

  5     WESTBOUND       .4958   .8958   0.4000                    0.0      .8958   .4958  0.6000    .4958   .8958  0.4000    0.0
        EASTBOUND       .4958   .8958   0.4000                    0.0      .8958   .4958  0.6000    .4958   .8958  0.4000    0.0
```

Figure 55: Continued.

```
                                                     (UU)
                                              PHASE SETTINGS -- SECONDS

                       - - - - GREEN - - - -    - - - - LEFT - - - -     - - - - RED - - - -     - - - - - - - - BAND - - - - - - - -
SIGNAL                                                                                                                     ADVANCED BY
  NO.   DIRECTION     BEGIN    END  DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION  QUEUE CLEAR
                                                                                                                              TIME

  1     WESTBOUND      0.0    36.4    36.4                     0.0      36.4     0.0    32.9       0.8    28.5    27.7       0.0
        EASTBOUND      0.0    36.4    36.4                     0.0      36.4     0.0    32.9       8.7    36.4    27.7       0.0

  2     WESTBOUND     37.1     4.1    36.4                     0.0       4.1    37.1    32.9      38.0    65.7    27.7       0.0
        EASTBOUND     37.1     4.1    36.4                     0.0       4.1    37.1    32.9      37.1    64.8    27.7       0.0

  3     WESTBOUND     62.8    35.0    41.6                     0.0      35.0    62.8    27.7      62.8    21.2    27.7       0.0
        EASTBOUND     62.B    35.0    41.6                     0.0      35.0    62.8    27.7       7.3    35.0    27.7       0.0

  4     WESTBOUND     59.9    34.8    44.2                     0.0      34.8    59.9    25.1       7.1    34.8    27.7       0.0
        EASTBOUND     59.9    34.8    44.2                     0.0      34.8    59.9    25.1      61.6    20.0    27.7       0.0

  5     WESTBOUND     34.4    62.1    27.7                     0.0      62.1    34.4    41.6      34.4    62.1    27.7       0.0
        EASTBOUND     34.4    62.1    27.7                     0.0      62.1    34.4    41.6      34.4    62.1    27.7       0.0

                                               PROGRESSION TIMES AND SPEEDS
                                  (WW)
                         (VV)          WESTBOUND      (XX)               (VV) (WW)      EASTBOUND       (XX)
                                   PROGRESSION     PROGRESSION                    PROGRESSION      PROGRESSION
         SIGNAL          LENGTH   TRAVERSAL TIME      SPEED             LENGTH   TRAVERSAL TIME       SPEED
           NO.           (FEET)       (SECS)     (MILES/HOUR)           (FEET)       (SECS)       (MILES/HOUR)

            1
                --------  1500.00      37.190        27.500            1500.00       40.909           25.000
            2
                --------  1000.00      24.793        27.500            1000.00       29.752           22.917
            3
                --------  550.000      13.636        27.500            550.000       15.000           25.000
            4
                --------  1100.00      27.273        27.500            1100.00       27.273           27.500
            5

      ENTIRE ARTERY       4150.00      102.89        27.500            4150.00       112.93           25.055
```

Figure 55: Continued.

(YY)

```
**** MAXBAND END ****
```

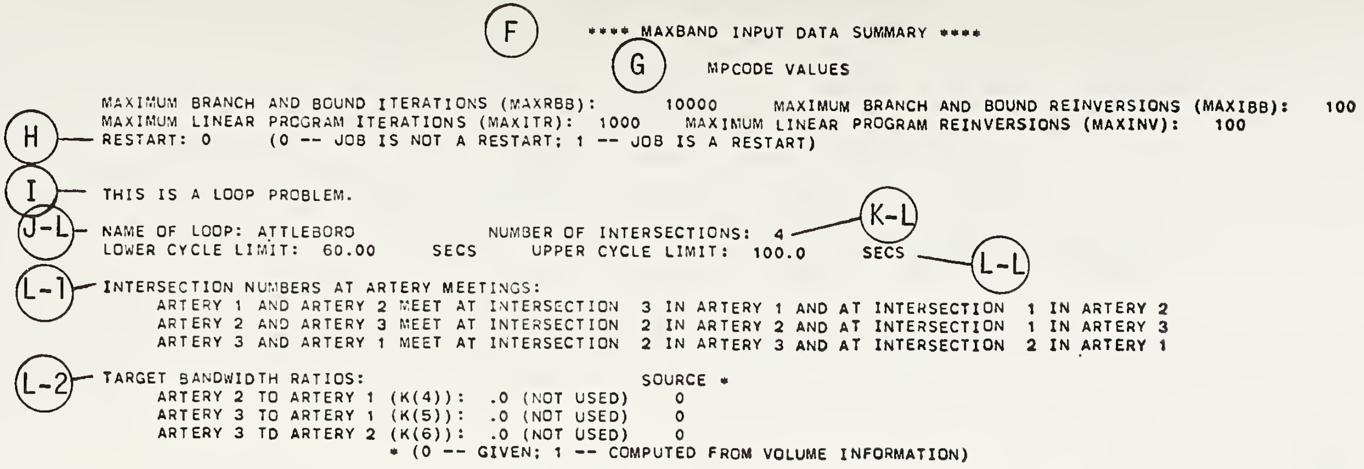
Figure 55: Continued.

```
                           Ⓐ    **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****
                                                  Ⓑ     **** MAXBAND INPUT CARDS ****
Ⓒ    START         0    0
     MPCODE         10000  100 1000  100    0
     SETUPL             4                                            ATTLEBORO
     LOOP1        60  100         3    1    2    2    2    1
     LOOP2         0    0    0
     SETUP1             3                   0              W         WASHINGTON ST
     ARTERY                                      1    3
     ART2          1    1    1   30    5    5   30    5    5
     MAP                3    1                                       BORROWS AVE
     SPECIFY                            .4300     .4300
     LENGTH
     MAP                2    2                                       HIGHLAND AVE
     SPECIFY                            .4200     .4200
     LENGTH                              1380
     MAP                1    3                                       NEWSPORT AVE
     SPECIFY                            .6000     .6000
     LENGTH                               860
     SETUP2             2                   0              N         NEWSPORT AVE
     ARTERY                                      1    2
     ART2          1    1    1   30    5    5   30    5    5
     MAP                1    1                                       WASHINGTON ST
     SPECIFY        .2500     .2500
     LENGTH
     MAP                4    2                                       HIGHLAND AVE
     SPECIFY        .3100     .3100
     LENGTH                     760
     SETUP3             2                   0              S         HIGHLAND AVE
     ARTERY                                      1    2
     ART2          1    1    1   30    5    5   30    5    5
     MAP                4    1                                       NEWSPORT AVE
     SPECIFY        .5400     .5400
     LENGTH
     MAP                2    2                                       WASHINGTON ST
     SPECIFY        .4300     .4300
     LENGTH           460
     END

Ⓓ      **** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES 3 AND 1
                           (INTERSECTION  2 IN ARTERY 3 AND INTERSECTION  2 IN ARTERY 1)
                           IS LESS THAN ONE CYCLE
                           (THERE IS ALL RED TIME OF 0.1500 CYCLES).

       **** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES 1 AND 2
                           (INTERSECTION  3 IN ARTERY 1 AND INTERSECTION  1 IN ARTERY 2)
                           IS LESS THAN ONE CYCLE
                           (THERE IS ALL RED TIME OF 0.1500 CYCLES).

       **** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES 2 AND 3
                           (INTERSECTION  2 IN ARTERY 2 AND INTERSECTION  1 IN ARTERY 3)
                           IS LESS THAN ONE CYCLE
                           (THERE IS ALL RED TIME OF 0.1500 CYCLES).
```

Figure 56: Output from Attleboro example of chapter 4.

```
Ⓔ  DATA HAS BEEN SUCCESSFULLY ENTERED.
```

Figure 56: Continued.


F
G
H
I
J-L
K-L
L-L
L-1
L-2

```
                        **** MAXBAND INPUT DATA SUMMARY ****
                                  MPCODE VALUES
MAXIMUM BRANCH AND BOUND ITERATIONS (MAXRBB):     10000     MAXIMUM BRANCH AND BOUND REINVERSIONS (MAXIBB):    100
MAXIMUM LINEAR PROGRAM ITERATIONS (MAXITR):  1000    MAXIMUM LINEAR PROGRAM REINVERSIONS (MAXINV):   100
RESTART: 0     (0 -- JOB IS NOT A RESTART; 1 -- JOB IS A RESTART)

THIS IS A LOOP PROBLEM.

NAME OF LOOP: ATTLEBORO            NUMBER OF INTERSECTIONS:  4
LOWER CYCLE LIMIT:  60.00     SECS     UPPER CYCLE LIMIT:  100.0     SECS

INTERSECTION NUMBERS AT ARTERY MEETINGS:
     ARTERY 1 AND ARTERY 2 MEET AT INTERSECTION  3 IN ARTERY 1 AND AT INTERSECTION  1 IN ARTERY 2
     ARTERY 2 AND ARTERY 3 MEET AT INTERSECTION  2 IN ARTERY 2 AND AT INTERSECTION  1 IN ARTERY 3
     ARTERY 3 AND ARTERY 1 MEET AT INTERSECTION  2 IN ARTERY 3 AND AT INTERSECTION  2 IN ARTERY 1

TARGET BANDWIDTH RATIOS:                             SOURCE *
     ARTERY 2 TO ARTERY 1 (K(4)):  .0 (NOT USED)     0
     ARTERY 3 TO ARTERY 1 (K(5)):  .0 (NOT USED)     0
     ARTERY 3 TD ARTERY 2 (K(6)):  .0 (NOT USED)     0
                       * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)
```

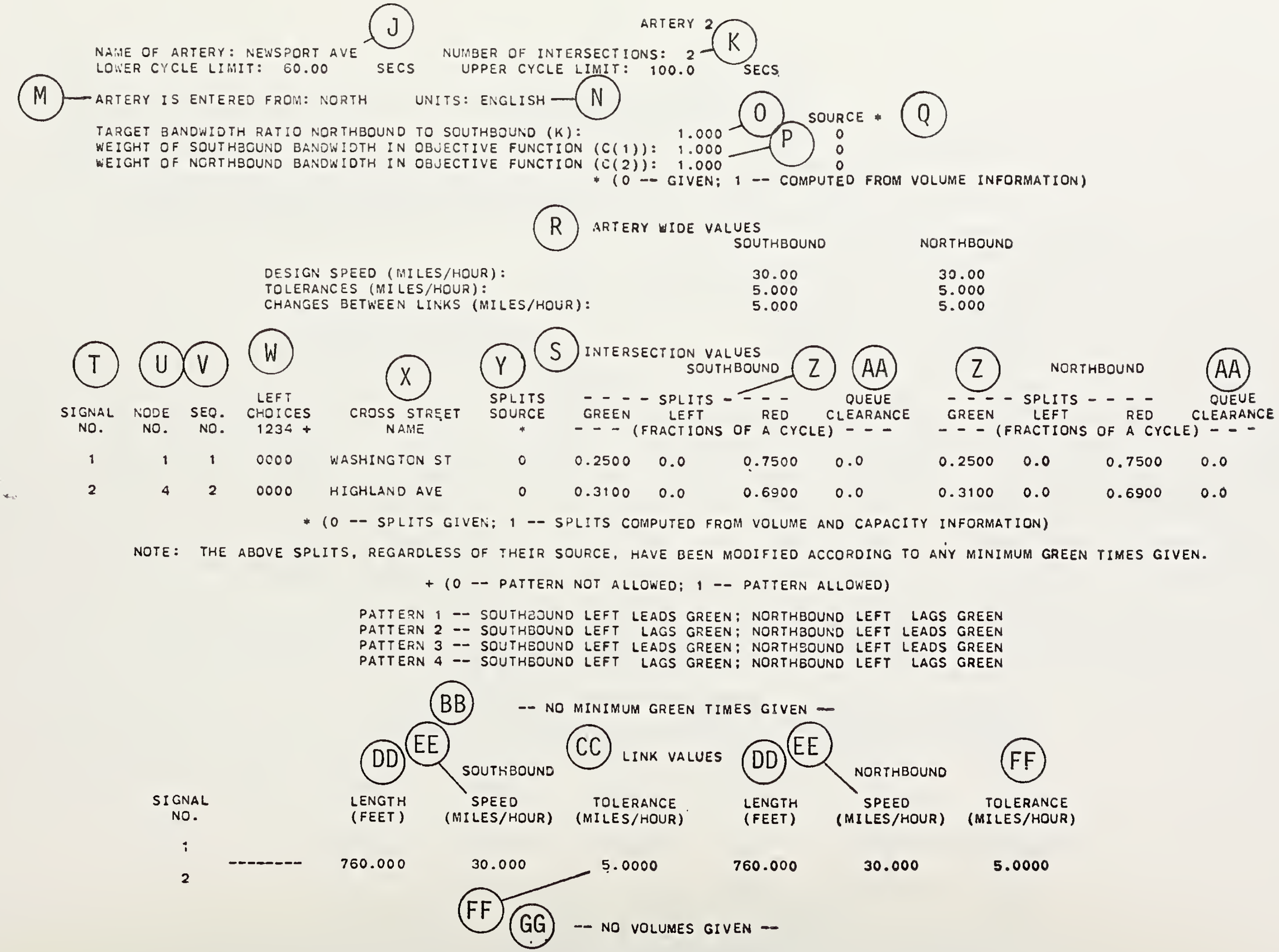
Figure 56: Continued.

```
                                                                   ARTERY 1    (K)
(J)  NAME OF ARTERY: WASHINGTON ST          NUMBER OF INTERSECTIONS:  3 /
     LOWER CYCLE LIMIT:  60.00     SECS     UPPER CYCLE LIMIT:  100.0      SECS

(M)- ARTERY IS ENTERED FROM:  WEST      UNITS: ENGLISH --(N)         (O)
                                                                          .SOURCE *  (Q)
     TARGET BANDWIDTH RATIO  WESTBOUND TO  EASTBOUND (K):          1.000     (P)  0
     WEIGHT OF  EASTBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(1)):  1.000          0
     WEIGHT OF  WESTBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(2)):  1.000          0
                                                         * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

                                        (R)   ARTERY WIDE VALUES
                                                          EASTBOUND          WESTBOUND

                  DESIGN SPEED (MILES/HOUR):                30.00              30.00
                  TOLERANCES (MILES/HOUR):                  5.000              5.000
                  CHANGES BETWEEN LINKS (MILES/HOUR):       5.000              5.000

                                      (Y)(S) INTERSECTION VALUES
 (T)    (U)   (V)    (W)        (X)                     EASTBOUND (Z)   (AA)       (Z)       WESTBOUND        (AA)
                     LEFT                        SPLITS   - - - - SPLITS - - - -     QUEUE      - - - - SPLITS - - - -       QUEUE
SIGNAL  NODE  SEQ.  CHOICES     CROSS STREET     SOURCE   GREEN    LEFT      RED    CLEARANCE   GREEN    LEFT      RED    CLEARANCE
 NO.    NO.   NO.   1234 +         NAME            *      - - - (FRACTIONS OF A CYCLE) - - -    - - - (FRACTIONS OF A CYCLE) - - -

  1      3     1    0000     BORROWS AVE           0      0.4300   0.0      0.5700   0.0        0.4300   0.0      0.5700    0.0

  2      2     2    0000     HIGHLAND AVE          0      0.4200   0.0      0.5800   0.0        0.4200   0.0      0.5800    0.0

  3      1     3    0000     NEWSPORT AVE          0      0.6000   0.0      0.4000   0.0        0.6000   0.0      0.4000    0.0

                * (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

      NOTE:  THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

                           + (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

                    PATTERN 1 --  EASTBOUND LEFT LEADS GREEN;  WESTBOUND LEFT  LAGS GREEN
                    PATTERN 2 --  EASTBOUND LEFT  LAGS GREEN;  WESTBOUND LEFT LEADS GREEN
                    PATTERN 3 --  EASTBOUND LEFT LEADS GREEN;  WESTBOUND LEFT LEADS GREEN
                    PATTERN 4 --  EASTBOUND LEFT  LAGS GREEN;  WESTBOUND LEFT  LAGS GREEN

                         (BB)   -- NO MINIMUM GREEN TIMES GIVEN --
```

Figure 56: Continued.

```
                        DD   EE                FF     CC            DD   EE                FF
                                  EASTBOUND        LINK VALUES              WESTBOUND
SIGNAL                LENGTH      SPEED       TOLERANCE        LENGTH      SPEED       TOLERANCE
 NO.                  (FEET)   (MILES/HOUR)  (MILES/HOUR)      (FEET)   (MILES/HOUR)  (MILES/HOUR)
  1
        ---------    1380.00      30.000       5.0000          1380.00      30.000       5.0000
  2
        ---------    860.000      30.000       5.0000          860.000      30.000       5.0000
  3

                           GG    -- NO VOLUMES GIVEN --

                           HH   -- NO CAPACITIES GIVEN --
```

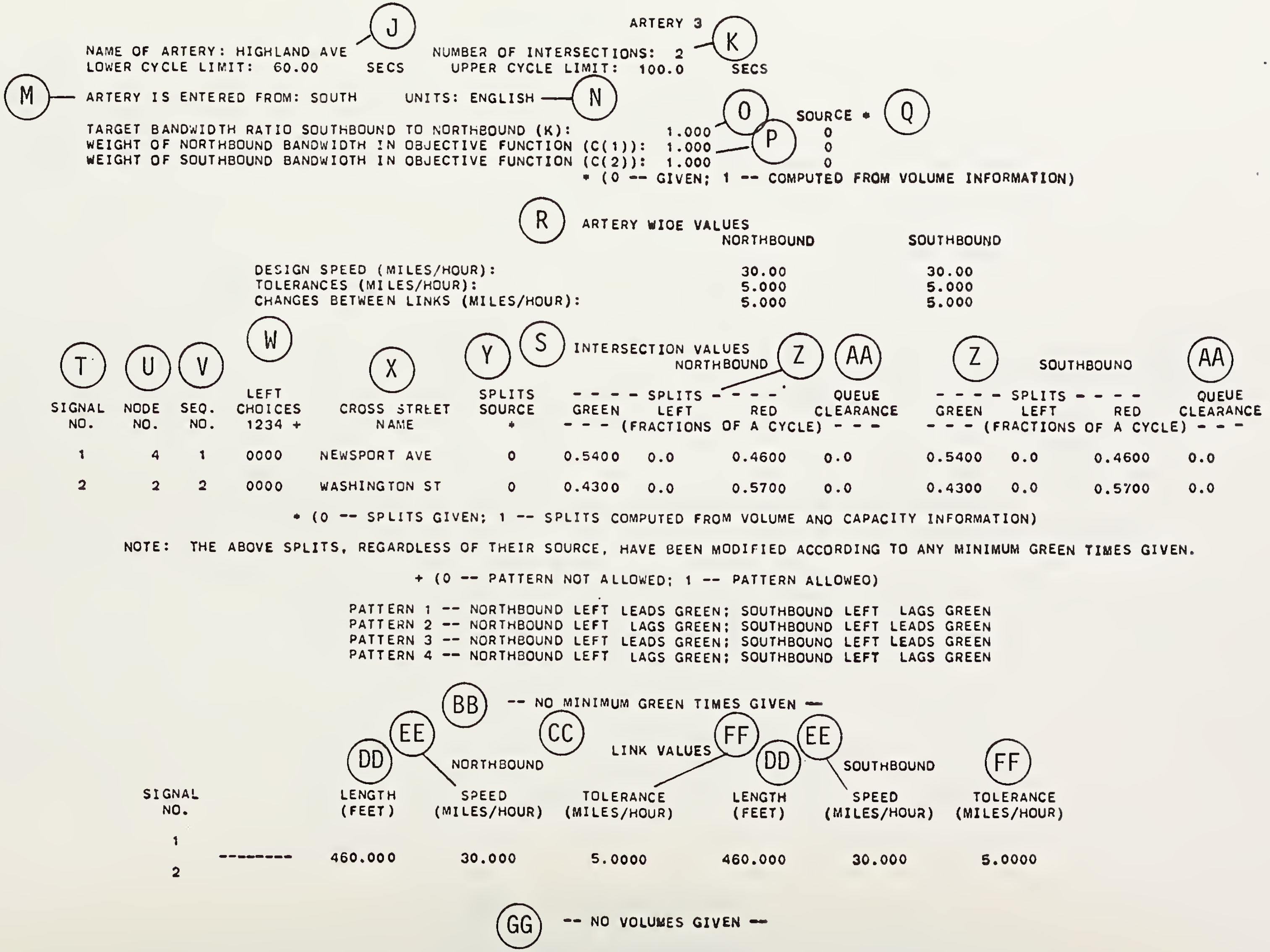
Figure 56: Continued.



```
                                                   ARTERY 2
NAME OF ARTERY: NEWSPORT AVE          NUMBER OF INTERSECTIONS:  2
LOWER CYCLE LIMIT:  60.00     SECS      UPPER CYCLE LIMIT:  100.0      SECS

ARTERY IS ENTERED FROM: NORTH      UNITS: ENGLISH
                                                                          SOURCE *
TARGET BANDWIDTH RATIO NORTHBOUND TO SOUTHBOUND (K):         1.000            0
WEIGHT OF SOUTHBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(1)):  1.000            0
WEIGHT OF NORTHBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(2)):  1.000            0
                                                  * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

                                      ARTERY WIDE VALUES
                                                   SOUTHBOUND          NORTHBOUND

           DESIGN SPEED (MILES/HOUR):                30.00               30.00
           TOLERANCES (MILES/HOUR):                  5.000               5.000
           CHANGES BETWEEN LINKS (MILES/HOUR):       5.000               5.000

                                          INTERSECTION VALUES
                                                  SOUTHBOUND                                NORTHBOUND
                      LEFT                      SPLITS    - - - - SPLITS - - - -    QUEUE        - - - - SPLITS - - - -      QUEUE
SIGNAL  NODE  SEQ.  CHOICES    CROSS STREET     SOURCE    GREEN    LEFT     RED   CLEARANCE      GREEN    LEFT     RED   CLEARANCE
  NO.    NO.   NO.   1234 +        NAME            *      - - - (FRACTIONS OF A CYCLE) - - -     - - - (FRACTIONS OF A CYCLE) - - -

   1      1     1    0000   WASHINGTON ST          0     0.2500   0.0     0.7500    0.0        0.2500   0.0     0.7500    0.0

   2      4     2    0000   HIGHLAND AVE           0     0.3100   0.0     0.6900    0.0        0.3100   0.0     0.6900    0.0

                  * (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

     NOTE:  THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

                         + (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

                    PATTERN 1 -- SOUTHBOUND LEFT LEADS GREEN; NORTHBOUND LEFT  LAGS GREEN
                    PATTERN 2 -- SOUTHBOUND LEFT  LAGS GREEN; NORTHBOUND LEFT LEADS GREEN
                    PATTERN 3 -- SOUTHBOUND LEFT LEADS GREEN; NORTHBOUND LEFT LEADS GREEN
                    PATTERN 4 -- SOUTHBOUND LEFT  LAGS GREEN; NORTHBOUND LEFT  LAGS GREEN

                                  -- NO MINIMUM GREEN TIMES GIVEN --

                                                 LINK VALUES
                                    SOUTHBOUND                                 NORTHBOUND
     SIGNAL
      NO.                LENGTH      SPEED        TOLERANCE      LENGTH       SPEED         TOLERANCE
                         (FEET)   (MILES/HOUR)  (MILES/HOUR)     (FEET)    (MILES/HOUR)   (MILES/HOUR)
       1
           --------      760.000     30.000        5.0000        760.000      30.000         5.0000
       2

                                      -- NO VOLUMES GIVEN --
```

Figure 56: Continued.

Figure 56: Continued.



```
                                                          ARTERY 3
NAME OF ARTERY: HIGHLAND AVE                NUMBER OF INTERSECTIONS:  2
LOWER CYCLE LIMIT:   60.00        SECS        UPPER CYCLE LIMIT:  100.0       SECS

ARTERY IS ENTERED FROM: SOUTH       UNITS: ENGLISH

                                                                              SOURCE *
TARGET BANDWIDTH RATIO SOUTHBOUND TO NORTHBOUND (K):            1.000          0
WEIGHT OF NORTHBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(1)):   1.000          0
WEIGHT OF SOUTHBOUND BANDWIOTH IN OBJECTIVE FUNCTION (C(2)):   1.000          0
                                                     * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

                                    ARTERY WIOE VALUES
                                                      NORTHBOUND          SOUTHBOUND

              DESIGN SPEED (MILES/HOUR):                30.00               30.00
              TOLERANCES (MILES/HOUR):                  5.000               5.000
              CHANGES BETWEEN LINKS (MILES/HOUR):       5.000               5.000

                                              INTERSECTION VALUES
                                                        NORTHBOUND                                SOUTHBOUND
                  LEFT                       SPLITS    - - - - SPLITS - - - -       QUEUE      - - - - SPLITS - - - -         QUEUE
SIGNAL  NODE  SEQ. CHOICES   CROSS STREET    SOURCE    GREEN    LEFT      RED    CLEARANCE     GREEN    LEFT      RED     CLEARANCE
 NO.    NO.   NO.  1234 +       NAME           *       - - - (FRACTIONS OF A CYCLE) - - -      - - - (FRACTIONS OF A CYCLE) - - -

  1      4     1   0000    NEWSPORT AVE        0     0.5400   0.0     0.4600    0.0         0.5400   0.0     0.4600    0.0

  2      2     2   0000    WASHINGTON ST       0     0.4300   0.0     0.5700    0.0         0.4300   0.0     0.5700    0.0

                * (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME ANO CAPACITY INFORMATION)

      NOTE:  THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

                        + (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWEO)

                  PATTERN 1 -- NORTHBOUND LEFT LEADS GREEN; SOUTHBOUND LEFT  LAGS GREEN
                  PATTERN 2 -- NORTHBOUND LEFT  LAGS GREEN; SOUTHBOUND LEFT LEADS GREEN
                  PATTERN 3 -- NORTHBOUND LEFT LEADS GREEN; SOUTHBOUNO LEFT LEADS GREEN
                  PATTERN 4 -- NORTHBOUND LEFT  LAGS GREEN; SOUTHBOUND LEFT  LAGS GREEN

                                  -- NO MINIMUM GREEN TIMES GIVEN --

                                                    LINK VALUES
                               NORTHBOUND                                    SOUTHBOUND
   SIGNAL          LENGTH        SPEED        TOLERANCE       LENGTH        SPEED        TOLERANCE
    NO.            (FEET)    (MILES/HOUR)   (MILES/HOUR)      (FEET)    (MILES/HOUR)   (MILES/HOUR)

     1
         --------  460.000       30.000        5.0000         460.000       30.000        5.0000
     2

                                    -- NO VOLUMES GIVEN --
```

Figure 56: Continued.

(HH) -- NO CAPACITIES GIVEN --

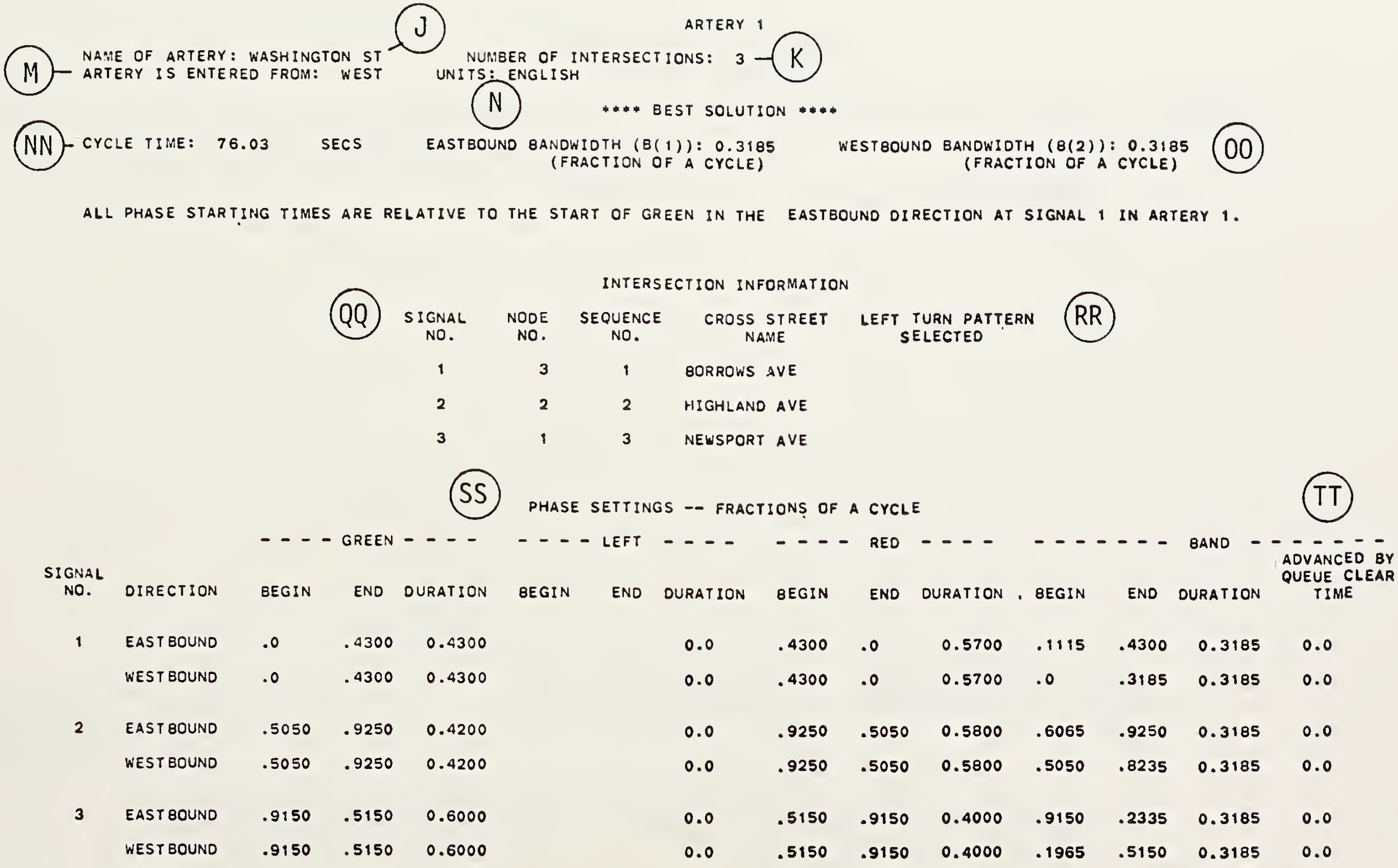
Figure 56: Continued.

```
(II)  MPCODE HAS SUCCESSFULLY COMPLETED.
       A REPORT BASED ON THE OPTIMAL SOLUTION WILL BE WRITTEN.  (JJ)

                                                  **** MPCODE STATISTICS ****

(KK)    NUMBER OF BRANCH AND BOUND ITERATIONS PERFORMED:        432     NUMBER OF BRANCH AND BOUND REINVERSIONS PERFORMED:

        MAXIMUM NUMBER OF ITERATIONS PERFORMED BY A LINEAR PROGRAM:    30
        MAXIMUM NUMBER OF REINVERSIONS PERFORMED BY A LINEAR PROGRAM:    0

(LL)--- NUMBER OF SOLUTIONS FOUND:          VALUE OF OBJECTIVE FUNCTION AT LAST SOLUTION:  1.54180 --(MM)
```

Figure 56: Continued.

```
                                        **** MAXBAND SOLUTION REPORT ****

       THIS IS A LOOP PROBLEM.   (I)
(J-L)──NAME OF LOOP: ATTLEBORO          NUMBER OF INTERSECTIONS:  4  (K-L)
(L-1)──INTERSECTION NUMBERS AT ARTERY MEETINGS:
          ARTERY 1 AND ARTERY 2 MEET AT INTERSECTION  3 IN ARTERY 1 AND AT INTERSECTION  1 IN ARTERY 2.
          ARTERY 2 AND ARTERY 3 MEET AT INTERSECTION  2 IN ARTERY 2 AND AT INTERSECTION  1 IN ARTERY 3.
          ARTERY 3 AND ARTERY 1 MEET AT INTERSECTION  2 IN ARTERY 3 AND AT INTERSECTION  2 IN ARTERY 1.
                                           **** BEST SOLUTION ****
(NN-L)─CYCLE TIME:  76.03     SECS
       BANDWIDTHS (FRACTIONS OF A CYCLE):     ARTERY 1:  EASTBOUND: 0.3185     WESTBOUND: 0.3185   (OO-L)
                                              ARTERY 2: SOUTHBOUND: 0.0853    NORTHBOUND: 0.0853
                                              ARTERY 3: NORTHBOUND: 0.3671    SOUTHBOUND: 0.3671
       OBJECTIVE FUNCTION:  1.54180 ─(PP-L)
```

Figure 56: Continued.


M
J
K
N
NN
OO
QQ
RR
SS
TT

```
                                                              ARTERY 1
     NAME OF ARTERY: WASHINGTON ST       NUMBER OF INTERSECTIONS:  3
     ARTERY IS ENTERED FROM:  WEST     UNITS: ENGLISH
                                                   **** BEST SOLUTION ****
     CYCLE TIME:  76.03      SECS      EASTBOUND BANDWIDTH (B(1)): 0.3185      WESTBOUND BANDWIDTH (B(2)): 0.3185
                                                 (FRACTION OF A CYCLE)                   (FRACTION OF A CYCLE)

     ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE  EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

                                                         INTERSECTION INFORMATION
                                       SIGNAL     NODE   SEQUENCE    CROSS STREET    LEFT TURN PATTERN
                                        NO.       NO.      NO.          NAME             SELECTED
                                         1         3        1       BORROWS AVE
                                         2         2        2       HIGHLAND AVE
                                         3         1        3       NEWSPORT AVE

                                                  PHASE SETTINGS -- FRACTIONS OF A CYCLE
                       - - - - GREEN - - - -    - - - - LEFT - - - -    - - - - RED - - - -    - - - - - - - BAND - - - - - - -
 SIGNAL                                                                                                                   ADVANCED BY
  NO.   DIRECTION      BEGIN    END  DURATION   BEGIN    END  DURATION  BEGIN    END  DURATION , BEGIN    END  DURATION   QUEUE CLEAR
                                                                                                                            TIME
   1    EASTBOUND      .0      .4300  0.4300                  0.0       .4300   .0     0.5700   .1115   .4300  0.3185     0.0
        WESTBOUND      .0      .4300  0.4300                  0.0       .4300   .0     0.5700   .0      .3185  0.3185     0.0

   2    EASTBOUND      .5050   .9250  0.4200                  0.0       .9250   .5050  0.5800   .6065   .9250  0.3185     0.0
        WESTBOUND      .5050   .9250  0.4200                  0.0       .9250   .5050  0.5800   .5050   .8235  0.3185     0.0

   3    EASTBOUND      .9150   .5150  0.6000                  0.0       .5150   .9150  0.4000   .9150   .2335  0.3185     0.0
        WESTBOUND      .9150   .5150  0.6000                  0.0       .5150   .9150  0.4000   .1965   .5150  0.3185     0.0
```

Figure 56: Continued.

```
                                                         (UU)
                                                PHASE SETTINGS -- SECONDS

                    - - - - GREEN - - - -   - - - - LEFT - - - -   - - - - .RED - - - -    - - - - - - - BAND - - - - - - -
SIGNAL                                                                                                            ADVANCED BY
  NO.   DIRECTION   BEGIN   END  DURATION   BEGIN   END  DURATION  BEGIN   END  DURATION   BEGIN   END  DURATION  QUEUE CLEAR
                                                                                                                      TIME

  1     EASTBOUND    0.0    32.7   32.7                     0.0     32.7    0.0   43.3      8.5   32.7   24.2        0.0
        WESTBOUND    0.0    32.7   32.7                     0.0     32.7    0.0   43.3      0.0   24.2   24.2        0.0

  2     EASTBOUND   38.4    70.3   31.9                     0.0     70.3   38.4   44.1     46.1   70.3   24.2        0.0
        WESTBOUND   38.4    70.3   31.9                     0.0     70.3   3B.4   44.1     3B.4   62.6   24.2        0.0

  3     EASTBOUND   69.6    39.2   45.6                     0.0     39.2   69.6   30.4     69.6   17.8   24.2        0.0
        WESTBOUND   69.6    39.2   45.6                     0.0     39.2   69.6   30.4     14.9   39.2   24.2        0.0


                                                PROGRESSION TIMES AND SPEEDS
                              (VV)  (WW)     EASTBOUND      (XX)              (VV)  (WW)     WESTBOUND       (XX)
                                           PROGRESSION    PROGRESSION                      PROGRESSION     PROGRESSION
          SIGNAL             LENGTH      TRAVERSAL TIME      SPEED           LENGTH      TRAVERSAL TIME       SPEED
            NO.              (FEET)          (SECS)      (MILES/HOUR)        (FEET)          (SECS)       (MILES/HOUR)
             1
                  --------   1380.00         37.636         25.000           1380.00         37.636          25.000
             2
                  --------   860.000         23.455         25.000           860.000         23.455          25.000
             3

       ENTIRE ARTERY         2240.00         61.091         25.000           2240.00         61.091          25.000
```

Figure 56: Continued.

```
                                                   (J)                          ARTERY 2
 (M)---NAME OF ARTERY: NEWSPORT AVE                       NUMBER OF INTERSECTIONS:  2--(K)
       ARTERY IS ENTERED FROM: NORTH               UNITS: ENGLISH
                                                      (N)       **** BEST SOLUTION ****
(NN)---CYCLE TIME:  76.03     SECS     SOUTHBOUND BANDWIDTH (B(1)): 0.0853     NORTHBOUND BANDWIDTH (B(2)): 0.0853  (OO)
                                                     (FRACTION OF A CYCLE)                (FRACTION OF A CYCLE)

       ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE  EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

                                                           INTERSECTION INFORMATION
                              (QQ)  SIGNAL    NODE   SEQUENCE    CROSS STREET   LEFT TURN PATTERN   (RR)
                                      NO.      NO.      NO.          NAME           SELECTED

                                      1        1        1      WASHINGTON ST

                                      2        4        2      HIGHLAND AVE

                                         (SS) PHASE SETTINGS -- FRACTIONS OF A CYCLE                               (TT)
                             - - - - GREEN - - - -  - - - - LEFT - - - -   - - - - RED - - - -   - - - - - - - BAND - - - - - - -
   SIGNAL                                                                                                            ADVANCED BY
    NO.   DIRECTION        BEGIN   END   DURATION   BEGIN   END  DURATION  BEGIN   END  DURATION  BEGIN   END  DURATION  QUEUE CLEAR
                                                                                                                         TIME

     1    SOUTHBOUND       .6650  .9150   0.2500                   0.0     .9150  .6650  0.7500   .6650  .7503  0.0853    0.0
          NORTHBOUND       .6650  .9150   0.2500                   0.0     .9150  .6650  0.7500   .8297  .9150  0.0853    0.0

     2    SOUTHBOUND       .6350  .9450   0.3100                   0.0     .9450  .6350  0.6900   .8597  .9450  0.0853    0.0
          NORTHBOUND       .6350  .9450   0.3100                   0.0     .9450  .6350  0.6900   .6350  .7203  0.0853    0.0
```

Figure 56: Continued.

```
                                                        (UU)
                                              PHASE SETTINGS -- SECONDS

                    - - - - GREEN - - - -   - - - - LEFT - - - -   - - - - RED - - - -   - - - - - - - BAND - - - - - - -
SIGNAL                                                                                                            ADVANCED BY
 NO.   DIRECTION    BEGIN   END  DURATION   BEGIN   END  DURATION   BEGIN   END  DURATION   BEGIN   END  DURATION  QUEUE CLEAR
                                                                                                                      TIME

  1    SOUTHBOUND   50.6   69.6    19.0                    0.0      69.6   50.6    57.0     50.6   57.0    6.5        0.0
       NORTHBOUND   50.6   69.6    19.0                    0.0      69.6   50.6    57.0     63.1   69.6    6.5        0.0

  2    SOUTHBOUND   48.3   71.9    23.6                    0.0      71.9   48.3    52.5     65.4   71.9    6.5        0.0
       NORTHBOUND   48.3   71.9    23.6                    0.0      71.9   48.3    52.5     48.3   54.8    6.5        0.0


                                              PROGRESSION TIMES AND SPEEDS
                          (VV)  (WW)      SOUTHBOUND   (XX)             (VV)  (WW)      NORTHBOUND     (XX)
                                  \                                           \
   SIGNAL                LENGTH    PROGRESSION     PROGRESSION         LENGTH    PROGRESSION      PROGRESSION
    NO.                  (FEET)  TRAVERSAL TIME       SPEED            (FEET)  TRAVERSAL TIME        SPEED
                                     (SECS)       (MILES/HOUR)                     (SECS)        (MILES/HOUR)
     1
          --------      760.000      14.805         35.000            760.000      14.805          35.000
     2
 ENTIRE ARTERY          760.000      14.805         35.000            760.000      14.805          35.000
```

Figure 56: Continued.

```
                                       (J)                          ARTERY 3
(M)——NAME OF ARTERY: HIGHLANO AVE ——/         NUMBER OF INTERSECTIONS:  2 ——(K)
   ——ARTERY IS ENTERED FROM: SOUTH         UNITS: ENGLISH
                                             (N)         **** BEST SOLUTION ****
(NN)——CYCLE TIME:  76.03     SECS     NORTHBOUNO BANOWIDTH (B(1)): 0.3671     SOUTHBOUNO BANDWIOTH (B(2)): 0.3671  (OO)
                                                 (FRACTION OF A CYCLE)                   (FRACTION OF A CYCLE)

      ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE  EASTBOUNO DIRECTION AT SIGNAL 1 IN ARTERY 1.

                                                   INTERSECTION INFORMATION
                     (QQ)     SIGNAL    NOOE   SEQUENCE    CROSS STREET    LEFT TURN PATTERN  (RR)
                                NO.      NO.      NO.         NAME             SELECTED
                                 1        4        1      NEWSPORT AVE
                                 2        2        2      WASHINGTON ST

                                    (SS)   PHASE SETTINGS -- FRACTIONS OF A CYCLE                                  (TT)
                            - - - - GREEN - - - -    - - - - LEFT - - - -    - - - - REO - - - -    - - - - - - - BANO - - - - - - -
SIGNAL                                                                                                                        ADVANCED BY
  NO.   OIRECTION     BEGIN    ENO   DURATION    BEGIN    ENO   OURATION    BEGIN    ENO   DURATION    BEGIN    ENO   OURATION   QUEUE CLEAR
                                                                                                                                 TIME

   1   NORTHBOUNO     .9450   .4850   0.5400                      0.0       .4850   .9450   0.4600    .9450   .3121   0.3671     0.0
       SOUTHBOUNO     .9450   .4850   0.5400                      0.0       .4850   .9450   0.4600    .1179   .4850   0.3671     0.0

   2   NORTHBOUND     .0      .4300   0.4300                      0.0       .4300   .0      0.5700    .0629   .4300   0.3671     0.0
       SOUTHBOUND     .0      .4300   0.4300                      0.0       .4300   .0      0.5700    .0      .3671   0.3671     0.0
```

Figure 56: Continued.

```
                                                        UU

                                              PHASE SETTINGS -- SECONDS

                          - - - - GREEN - - - -   - - - - LEFT - - - -   - - - - RED - - - -   - - - - - - - BAND - - - - - - -
SIGNAL                                                                                                                 ADVANCED BY
 NO.    DIRECTION      BEGIN   END  DURATION   BEGIN   END  DURATION   BEGIN   END  DURATION   BEGIN   END  DURATION  QUEUE CLEAR
                                                                                                                          TIME

  1    NORTHBOUND      71.9   36.9    41.1                    0.0      36.9   71.9    35.0     71.9   23.7    27.9        0.0
       SOUTHBOUND      71.9   36.9    41.1                    0.0      36.9   71.9    35.0      9.0   36.9    27.9        0.0

  2    NORTHBOUND       0.0   32.7    32.7                    0.0      32.7    0.0    43.3      4.8   32.7    27.9        0.0
       SOUTHBOUND       0.0   32.7    32.7                    0.0      32.7    0.0    43.3      0.0   27.9    27.9        0.0


                                              PROGRESSION TIMES AND SPEEDS
                              VV    WW     NORTHBOUND        XX              VV    WW     SOUTHBOUND        XX
                                          PROGRESSION    PROGRESSION                    PROGRESSION     PROGRESSION
     SIGNAL                 LENGTH      TRAVERSAL TIME      SPEED          LENGTH     TRAVERSAL TIME      SPEED
      NO.                   (FEET)          (SECS)      (MILES/HOUR)       (FEET)         (SECS)      (MILES/HOUR)

       1
              --------     460.000         8.9610         35.000          460.000         8.9610         35.000
       2

  ENTIRE ARTERY            460.000         8.9610         35.000          460.000         8.9610         35.000
```

Figure 56: Continued.

```
                              **** REITERATION OF SETTINGS AT ARTERY MEETINGS ****
          ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE  EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.
   (L-3)-----  ARTERY 1 AND ARTERY 2 MEET AT INTERSECTION  3 IN ARTERY 1 AND AT INTERSECTION  1 IN ARTERY 2.
(L-4)                                          PHASE SETTINGS -- FRACTIONS OF A CYCLE
             \             - - - - GREEN - - - -    - - - - LEFT - - - -    - - - - RED - - - -    - - - - - - - BAND - - - - - - -
            DIRECTION                                                                                                     ADVANCED BY
   SIGNAL   3 IN                                                                                                          QUEUE CLEAR
     ARTERY 1:             BEGIN    END  DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION     TIME
            EASTBOUND      .9150   .5150   0.6000                   0.0      .5150   .9150   0.4000   .9150   .2335   0.3185     0.0
(L-5)       WESTBOUND      .9150   .5150   0.6000                   0.0      .5150   .9150   0.4000   .1965   .5150   0.3185     0.0
      \
      SIGNAL   1  IN
        ARTERY  2:
           SOUTHBOUND      .6650   .9150   0.2500                   0.0      .9150   .6650   0.7500   .6650   .7503   0.0853     0.0
           NORTHBOUND      .6650   .9150   0.2500                   0.0      .9150   .6650   0.7500   .8297   .9150   0.0853     0.0
(L-6)--  ALL RED TIMES  --  BEFORE ARTERY 2 PHASE:  .5150   .6650   0.1500    AFTER ARTERY 2 PHASE:   .9150   .9150   0.0
                                                      PHASE SETTINGS -- SECONDS
(L-7)---                   - - - - GREEN - - - -    - - - - LEFT - - - -    - - - - RED - - - -    - - - - - - - BAND - - - - - - -
            DIRECTION                                                                                                     ADVANCED BY
   SIGNAL   3 IN                                                                                                          QUEUE CLEAR
     ARTERY 1:             BEGIN    END  DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION   BEGIN    END  DURATION     TIME
            EASTBOUND       69.6    39.2    45.6                     0.0      39.2    69.6    30.4     69.6    17.8    24.2       0.0
            WESTBOUND       69.6    39.2    45.6                     0.0      39.2    69.6    30.4     14.9    39.2    24.2       0.0
      SIGNAL   1  IN
        ARTERY  2:
           SOUTHBOUND       50.6    69.6    19.0                     0.0      69.6    50.6    57.0     50.6    57.0     6.5       0.0
           NORTHBOUND       50.6    69.6    19.0                     0.0      69.6    50.6    57.0     63.1    69.6     6.5       0.0

      ALL RED TIMES  --  BEFORE ARTERY 2 PHASE:   39.2    50.6    11.4    AFTER ARTERY 2 PHASE:    69.6    69.6     0.0
```

Figure 56: Continued.

```
(L-3)——— ARTERY 2 AND ARTERY 3 MEET AT INTERSECTION  2 IN ARTERY 2 AND AT INTERSECTION  1 IN ARTERY 3.

(L-4)                             PHASE SETTINGS -- FRACTIONS OF A CYCLE

                      - - - - GREEN - - - -    - - - - LEFT - - - -    - - - - RED - - - -    - - - - - - - BAND - - - - - - -
        DIRECTION                                                                                                  ADVANCED BY
   SIGNAL  2 IN                                                                                                    QUEUE CLEAR
     ARTERY 2:         BEGIN    END  DURATION  BEGIN    END  DURATION  BEGIN    END  DURATION  BEGIN    END  DURATION    TIME

          SOUTHBOUND   .6350  .9450   0.3100                     0.0   .9450  .6350   0.6900   .8597  .9450   0.0853    0.0
(L-5)     NORTHBOUND   .6350  .9450   0.3100                     0.0   .9450  .6350   0.6900   .6350  .7203   0.0853    0.0
    SIGNAL  1 IN
      ARTERY 3:

          NORTHBOUND   .9450  .4850   0.5400                     0.0   .4850  .9450   0.4600   .9450  .3121   0.3671    0.0
          SOUTHBOUND   .9450  .4850   0.5400                     0.0   .4850  .9450   0.4600   .1179  .4850   0.3671    0.0

(L-6)— ALL RED TIMES --  BEFORE ARTERY 3 PHASE:  .9450  .9450   0.0    AFTER ARTERY 3 PHASE:  .4850  .6350   0.1500

                                     PHASE SETTINGS -- SECONDS
(L-7)
                      - - - - GREEN - - - -    - - - - LEFT - - - -    - - - - RED - - - -    - - - - - - - BAND - - - - - - -
        DIRECTION                                                                                                  ADVANCED BY
   SIGNAL  2 IN                                                                                                    QUEUE CLEAR
     ARTERY 2:         BEGIN    END  DURATION  BEGIN    END  DURATION  BEGIN    END  DURATION  BEGIN    END  DURATION    TIME

          SOUTHBOUND    48.3   71.9    23.6                      0.0    71.9   48.3    52.5     65.4   71.9     6.5      0.0
          NORTHBOUND    48.3   71.9    23.6                      0.0    71.9   48.3    52.5     48.3   54.8     6.5      0.0
    SIGNAL  1 IN
      ARTERY 3:

          NORTHBOUND    71.9   36.9    41.1                      0.0    36.9   71.9    35.0     71.9   23.7    27.9      0.0
          SOUTHBOUND    71.9   36.9    41.1                      0.0    36.9   71.9    35.0      9.0   36.9    27.9      0.0

    ALL RED TIMES --  BEFORE ARTERY 3 PHASE:   71.9   71.9     0.0   AFTER ARTERY 3 PHASE:    36.9   48.3    11.4
```

Figure 56: Continued.

```
(L-3)────── ARTERY 3 AND ARTERY 1 MEET AT INTERSECTION  2 IN ARTERY 3 AND AT INTERSECTION  2 IN ARTERY 1.

                                          PHASE SETTINGS -- FRACTIONS OF A CYCLE
(L-4)
         DIRECTION   - - - - GREEN - - - -   - - - - LEFT - - - -   - - - - RED - - - -    - - - - - - - BAND - - - - - - -
   SIGNAL  2 IN                                                                                                    ADVANCED BY
    ARTERY 3:                                                                                                      QUEUE CLEAR
                     BEGIN    END  DURATION  BEGIN   END  DURATION  BEGIN    END  DURATION  BEGIN    END  DURATION    TIME
        NORTHBOUND   .0      .4300  0.4300                  0.0     .4300   .0     0.5700   .0629  .4300  0.3671      0.0
(L-5)   SOUTHBOUND   .0      .4300  0.4300                  0.0     .4300   .0     0.5700   .0     .3671  0.3671      0.0
    SIGNAL  2 IN
      ARTERY 1:
         EASTBOUND   .5050   .9250  0.4200                  0.0     .9250  .5050   0.5800   .6065  .9250  0.3185      0.0
         WESTBOUND   .5050   .9250  0.4200                  0.0     .9250  .5050   0.5800   .5050  .8235  0.3185      0.0

(L-6)── ALL RED TIMES  --  BEFORE ARTERY 1 PHASE:  .4300  .5050  0.0750   AFTER ARTERY 1 PHASE:  .9250  .0   0.0750

                                               PHASE SETTINGS -- SECONDS
(L-7)
         DIRECTION   - - - - GREEN - - - -   - - - - LEFT - - - -   - - - - RED - - - -    - - - - - - - BAND - - - - - - -
   SIGNAL  2 IN                                                                                                    ADVANCED BY
    ARTERY 3:                                                                                                      QUEUE CLEAR
                     BEGIN    END  DURATION  BEGIN   END  DURATION  BEGIN    END  DURATION  BEGIN    END  DURATION    TIME
        NORTHBOUND    0.0    32.7   32.7                    0.0     32.7    0.0    43.3      4.8    32.7   27.9       0.0
        SOUTHBOUND    0.0    32.7   32.7                    0.0     32.7    0.0    43.3      0.0    27.9   27.9       0.0
    SIGNAL  2 IN
      ARTERY 1:
         EASTBOUND   38.4    70.3   31.9                    0.0     70.3   38.4    44.1     46.1    70.3   24.2       0.0
         WESTBOUND   38.4    70:3   31.9                    0.0     70.3   38.4    44.1     38.4    62.6   24.2       0.0

    ALL RED TIMES  --  BEFORE ARTERY 1 PHASE:   32.7   38.4    5.7   AFTER ARTERY 1 PHASE:   70.3   0.0    5.7
```

Figure 56: Continued.

YY

```
**** MAXBAND END ****
```

Figure 56: Continued.

```
                           **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****

                                                  **** MAXBAND INPUT CARDS ****

START         0    0
COMM     THIS DECK PRODUCES WARNING AND ERROR MESSAGES.
MPCODE         10000  100 1000  100   0
SETUP             24                  0               T        WALTHAM 6-SIGNAL

  **** ERROR ****  ILLEGAL NUMBER OF INTERSECTIONS IN ARTERY.


  **** ERROR ****  BAD ENTRY DIRECTION.

ARTERY       60   45                       1    6

  **** ERROR ****  LOWER CYCLE TIME LIMIT IS GREATER THAN UPPER CYCLE TIME LIMIT.

ART2          1    1    1  20     2    2   20   2    2
MAP              101    0                                      BANKS

  **** WARNING ****  SEQUENCE NUMBER NOT IN ACCEPTABLE RANGE.


  **** WARNING ****  SEQUENCE NUMBER OF FIRST INTERSECTION IS NOT ONE.

GARBAGE

  **** ERROR ****  'GARBAGE ' NOT A VALID CARD.

SPECIFY        .6875.1500.5375   6
SPECIFY

  **** WARNING ****  A DUPLICATE SPECIFY CARD HAS BEEN READ.  IT HAS BEEN IGNORED.

LENGTH
LEFTPAT       1    1
MAP              102    2                                      PROSPECT

  **** WARNING ****  SEQUENCE NUMBERS ARE NOT IN ORDER.

SPECIFY        .4375     .4375
LENGTH           810

  **** WARNING ****  END OF FILE HAS BEEN REACHED WITHOUT AN END CARD.


  **** WARNING ****  NUMBER OF INTERSECTIONS ENTERED DOES NOT AGREE WITH NUMBER ON SETUP CARD.


      4 ERRORS
 DATA INPUT NOT SUCCESSFUL.  JOB TERMINATING.

                                                      **** MAXBAND END ****
```

Figure 57: Output with warning and error messages.

```
                         **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****

                                                   **** MAXBAND INPUT CARDS ****
COMM      THE MESSAGE LEVEL HAS BEEN SET TO ONE HERE.
COMM      NOTE THAT COMM CARDS PLACED BEFORE THE START CARD, AND THE START CARD
COMM       ITSELF, ARE STILL PRINTED.
START           1     0

  **** ERROR ****  ILLEGAL NUMBER OF INTERSECTIONS IN ARTERY.


  **** ERROR **** 'BAD ENTRY DIRECTION.


  **** ERROR ****  LOWER CYCLE TIME LIMIT IS GREATER THAN UPPER CYCLE TIME LIMIT.


  **** WARNING ****  SEQUENCE NUMBER NOT IN ACCEPTABLE RANGE.


  **** WARNING ****  SEQUENCE NUMBER OF FIRST INTERSECTION IS NOT ONE.


  **** ERROR ****  'GARBAGE ' NOT A VALID CARD.


  **** WARNING ****  A DUPLICATE SPECIFY CARD HAS BEEN READ.  IT HAS BEEN IGNORED.


  **** WARNING ****  SEQUENCE NUMBERS ARE NOT IN ORDER.


  **** WARNING ****  END OF FILE HAS BEEN REACHED WITHOUT AN END CARD.


  **** WARNING ****  NUMBER OF INTERSECTIONS ENTERED DOES NOT AGREE WITH NUMBER ON SETUP CARD.


      4 ERRORS
 DATA INPUT NOT SUCCESSFUL.  JOB TERMINATING.
                                                   **** MAXBAND END ****
```

Figure 58: Output of figure 57 with message level at 1 and warning level at 0.

```
                            **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****

                                                    **** MAXBAND INPUT CARDS ****
COMM     THE WARNING LEVEL HAS BEEN SET TO ONE HERE.
START          0    1
COMM     THIS DECK PRODUCES WARNING AND ERROR MESSAGES.
MPCODE          10000  100 1000  100     0
SETUP              24                    0               T        WALTHAM 6-SIGNAL

  **** ERROR ****  ILLEGAL NUMBER OF INTERSECTIONS IN ARTERY.


  **** ERROR ****  BAD ENTRY DIRECTION.

ARTERY       60   45                          1    6

  **** ERROR ****  LOWER CYCLE TIME LIMIT IS GREATER THAN UPPER CYCLE TIME LIMIT.

ART2           1    1    1   20    2    2   20    2    2
MAP               101    0                                        BANKS
GARBAGE

  **** ERROR ****  'GARBAGE ' NOT A VALID CARD.

SPECIFY         .6875.1500.5375    0
SPECIFY
LENGTH
LEFTPAT        1    1
MAP               102    2                                        PROSPECT
SPECIFY         .4375     .4375
LENGTH            810

      4 ERRORS
 DATA INPUT NOT SUCCESSFUL.  JOB TERMINATING.

                                                        **** MAXBAND END ****
```

Figure 59: Output of figure 57 with message level at 0 and warning level at 1.

Appendix A

MAXBAND INPUT WARNING AND ERROR MESSAGES.

The following two sections contain the MAXBAND input warning and error messages. After each message is the name of the card (if any) which is most closely associated with it.

A.1 INPUT WARNING MESSAGES.

**** WARNING ****	NO START CARD. DEFAULT VALUE FOR MESSAGE LEVEL AND WARNING LEVEL ASSUMED.	START
**** WARNING ****	NUMBER OF INTERSECTIONS ENTERED DOES NOT AGREE WITH NUMBER ON SETUP CARD.	SETUP MAP
**** WARNING ****	NON-INTERSECTION SPECIFIC CARD. IT HAS BEEN IGNORED.	
**** WARNING ****	NUMBER OF INTERSECTIONS ENTERED ON SETUPL CARD DOES NOT AGREE WITH NUMBER READ IN.	SETUPL
**** WARNING ****	END OF FILE HAS BEEN REACHED WITHOUT AN END CARD.	END
**** WARNING ****	BAD VALUE GIVEN FOR MESSAGE LEVEL. ZERO ASSUMED.	START
**** WARNING ****	BAD VALUE GIVEN FOR WARNING LEVEL. ZERO ASSUMED.	START
**** WARNING ****	LAST INTERSECTION NUMBER IS GREATER THAN NUMBER ON SETUP CARD.	SETUP ARTERY
**** WARNING ****	SEQUENCE NUMBER NOT IN ACCEPTABLE RANGE.	MAP
**** WARNING ****	SEQUENCE NUMBER OF FIRST INTERSECTION IS NOT ONE.	MAP
**** WARNING ****	SEQUENCE NUMBERS ARE NOT IN ORDER.	MAP
**** WARNING ****	A DUPLICATE SPECIFY CARD HAS BEEN READ. IT HAS BEEN IGNORED.	SPECIFY

**** WARNING ****	A DUPLICATE LENGTH CARD HAS BEEN READ. IT HAS BEEN IGNORED.	LENGTH
**** WARNING ****	A DUPLICATE LEFTPAT CARD HAS BEEN READ. IT HAS BEEN IGNORED.	LEFTPAT
**** WARNING ****	BAD VALUE ENCOUNTERED IN LEFTPAT CARD. ASSUMED TO BE ZERO.	LEFTPAT
**** WARNING ****	A DUPLICATE SPEED CARD HAS BEEN READ. IT HAS BEEN IGNORED.	SPEED
**** WARNING ****	A DUPLICATE QUEUE CARD HAS BEEN READ. IT HAS BEEN IGNORED.	QUEUE
**** WARNING ****	A DUPLICATE VOLUME CARD HAS BEEN ENCOUNTERED. IT HAS BEEN IGNORED.	VOLUME
**** WARNING ****	A DUPLICATE CAPACITY CARD HAS BEEN READ. IT HAS BEEN IGNORED.	CAPACITY
**** WARNING ****	A DUPLICATE MINGREEN CARD HAS BEEN READ. IT HAS BEEN IGNORED.	MINGREEN
**** WARNING ****	LAST INTERSECTION SPECIFIED FOR ARTERY X EXCEEDS ACTUAL NUMBER ENTERED. ARTERY WILL BE ANALYZED UP TO LAST INTERSECTION ACTUALLY ENTERED.	ARTERY MAP
**** WARNING ****	THERE IS NO VOLUME ON ARTERY X. IF K,C(1), OR C(2) ARE TO BE COMPUTED FROM VOLUME DATA, THEY HAVE BEEN SET TO ONE.	VOLUME ART2
**** WARNING ****	K(4) IS TO BE SET BUT VOLUMES ON ARTERY 1 ARE ZERO. K(4) IS ASSUMED ZERO.	VOLUME LOOP2
**** WARNING ****	K(5) IS TO BE SET BUT VOLUMES ON ARTERY 1 ARE ZERO. K(5) IS ASSUMED ZERO.	VOLUME LOOP2
**** WARNING ****	K(6) IS TO BE SET BUT VOLUMES ON ARTERY 2 ARE ZERO. K(6) IS ASSUMED ZERO.	VOLUME LOOP2
**** WARNING ****	THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES X AND X (INTERSECTION XX IN ARTERY X AND INTERSECTION XX IN ARTERY X) IS LESS THAN ONE CYCLE (THERE IS ALL RED TIME OF X.XXXX CYCLES).	SPECIFY LOOP1

A.2 INPUT ERROR MESSAGES.

**** ERROR **** NO SETUP OR SETUPL CARD FOUND.	SETUP SETUPL
**** ERROR **** NO ARTERY CARD	ARTERY
**** ERROR **** NO ART2 CARD.	ART2
**** ERROR **** NO MAP CARD.	MAP
**** ERROR **** ARTERY HAS LESS THAN 2 INTERSECTIONS.	MAP
**** ERROR **** ARTERY HAS MORE THAN 20 INTERSECTIONS.	MAP
**** ERROR **** ARTERY HAS MORE THAN 16 INTERSECTIONS.	MAP
**** ERROR **** NO LOOP1 CARD.	LOOP1
**** ERROR **** NO SETUPi CARD.	SETUP1 SETUP2 SETUP3
**** ERROR **** 'XXXXXXXX' NOT A VALID CARD.	
**** ERROR **** END OF FILE HAS BEEN REACHED PREMATURELY.	END
**** ERROR **** AN ILLEGAL VALUE FOUND ON MPCODE CARD.	MPCODE
**** ERROR **** ILLEGAL NUMBER OF INTERSECTIONS IN ARTERY.	SETUP
**** ERROR **** BAD ENTRY DIRECTION.	SETUP
**** ERROR **** ILLEGAL NUMBER OF INTERSECTIONS IN LOOP.	SETUPL
**** ERROR **** BAD CYCLE TIME LIMIT.	ARTERY
**** ERROR **** LOWER CYCLE TIME LIMIT IS GREATER THAN UPPER CYCLE TIME LIMIT.	ARTERY
**** ERROR **** ILLEGAL VALUE FOR FIRST OR LAST INTERSECTION.	ARTERY
**** ERROR **** FIRST INTERSECTION HAS A NUMBER HIGHER THAN OR EQUAL TO THAT OF LAST.	ARTERY
**** ERROR **** NO SPEED INFORMATION ON ART2 CARD.	ART2
**** ERROR **** ILLEGAL SPEED, TOLERANCE, OR CHANGE VALUE.	ART2
**** ERROR **** LOWER AND UPPER CYCLE TIMES MUST BE GREATER THAN ZERO.	LOOP1

**** ERROR ****	LOWER CYCLE LIMIT CANNOT BE GREATER THAN UPPER CYCLE LIMIT.	LOOP1
**** ERROR ****	AN INTERSECTION NUMBER AT ONE OF THE ARTERY INTERSECTIONS IS OUT OF THE ACCEPTABLE RANGE 1 - 16.	LOOP1
**** ERROR ****	NO LENGTH CARD FOR PREVIOUS INTERSECTION.	LENGTH
**** ERROR ****	NO VOLUME, CAPACITY OR SPECIFY CARDS FOR PREVIOUS INTERSECTION.	VOLUME CAPACITY SPECIFY
**** ERROR ****	NO SPECIFY OR CAPACITY CARD FOR PREVIOUS INTERSECTION.	SPECIFY CAPACITY
**** ERROR ****	NO SPECIFY OR VOLUME CARD FOR PREVIOUS INTERSECTION.	SPECIFY VOLUME
**** ERROR ****	NO MAIN STREET THROUGH SPLITS GIVEN.	SPECIFY
**** ERROR ****	NEGATIVE THROUGH SPLIT ENCOUNTERED.	SPECIFY
**** ERROR ****	NEGATIVE LEFT SPLIT ENCOUNTERED.	SPECIFY
**** ERROR ****	GIVEN SPLITS EXCEED 100 PER CENT OF CYCLE.	SPECIFY
**** ERROR ****	NO LENGTH VALUES GIVEN.	LENGTH
**** ERROR ****	ZERO OR NEGATIVE LENGTH ENCOUNTERED.	LENGTH
**** ERROR ****	ZERO OR NEGATIVE SPEED ENCOUNTERED.	SPEED
**** ERROR ****	NEGATIVE TOLERANCE ENCOUNTERED.	SPEED
**** ERROR ****	QUEUE CLEARANCE TIME NEGATIVE OR GREATER THAN ONE.	QUEUE
**** ERROR ****	NO THROUGH VOLUME INFORMATION GIVEN FOR AT LEAST ONE OF THE PHASES AT THIS INTERSECTION.	VOLUME
**** ERROR ****	NEGATIVE THROUGH VOLUME ENCOUNTERED.	VOLUME
**** ERROR ****	NEGATIVE LEFT VOLUME ENCOUNTERED.	VOLUME
**** ERROR ****	BOTH VOLUMES ARE ZERO FOR AT LEAST ONE PHASE AT THIS INTERSECTION.	VOLUME
**** ERROR ****	NO THROUGH CAPACITY INFORMATION GIVEN FOR AT LEAST ONE PHASE AT THIS INTERSECTION.	CAPACITY
**** ERROR ****	NEGATIVE THROUGH CAPACITY ENCOUNTERED.	CAPACITY
**** ERROR ****	NEGATIVE LEFT CAPACITY ENCOUNTERED.	CAPACITY

**** ERROR ****	BOTH CAPACITIES ARE ZERO FOR AT LEAST ONE PHASE AT THIS INTERSECTION.	CAPACITY
**** ERROR ****	NEGATIVE THROUGH MINIMUM GREEN TIME ENCOUNTERED.	MINGREEN
**** ERROR ****	NEGATIVE LEFT MINIMUM GREEN TIME ENCOUNTERED.	MINGREEN
**** ERROR ****	TOTAL OF MINIMUM GREEN TIMES EXCEEDS ONE CYCLE.	MINGREEN
**** ERROR ****	THE FIRST AND LAST INTERSECTIONS IN ARTERY X TO BE USED DO NOT SPECIFY AT LEAST TWO INTERSECTIONS.	ARTERY MAP
**** ERROR ****	IT HAS BEEN REQUESTED THAT K, C(1), OR C(2) BE COMPUTED FROM VOLUME INFORMATION FOR ARTERY X, BUT VOLUME INFORMATION HAS NOT BEEN SUPPLIED FOR EVERY INTERSECTION.	VOLUME ART2
**** ERROR ****	A THROUGH VOLUME EXCEEDS CAPACITY AT SIGNAL XX IN ARTERY X	VOLUME CAPACITY
**** ERROR ****	A LEFT VOLUME EXCEEDS CAPACITY AT SIGNAL XX IN ARTERY X	VOLUME CAPACITY
**** ERROR ****	NO GIVEN SPLITS OR VOLUME OR CAPACITY INFORMATION FOR INTERSECTION XX OF ARTERY X.	SPECIFY VOLUME CAPACITY
**** ERROR ****	A TOLERANCE IS GREATER THAN DESIGN SPEED ALONG SOME LINK OF ARTERY X.	ART2 SPEED
**** ERROR ****	A CHANGE VALUE EXCEEDS OR EQUALS THE MINIMUM OF UPPER SPEED LIMITS OF LINKS ALONG ARTERY X.	ART2 SPEED
**** ERROR ****	A CHANGE OF SPEED VALUE IS NOT LARGE ENOUGH ON ARTERY X.	ART2 SPEED
**** ERROR ****	COMPUTATION OF ONE OF K(4) - K(6) HAS BEEN REQUESTED, BUT VOLUME INFORMATION HAS NOT BEEN PROVIDED FOR EVERY INTERSECTION OF ARTERY X.	VOLUME LOOP2
**** ERROR ****	ARTERY X SHOULD JOIN ANOTHER ARTERY AT INTERSECTION XX BUT THIS INTERSECTION IS OUT OF RANGE OF INTERSECTIONS ACTUALLY ENTERED.	LOOP1 MAP
**** ERROR ****	BAD LOOP GEOMETRY. THE SAME INTERSECTION HAS BEEN SPECIFIED FOR BOTH MEETINGS OF ARTERY X.	LOOP1
**** ERROR ****	TOTAL OF SPLITS GIVEN FOR INTERSECTION OF ARTERIES X AND X EXCEEDS ONE CYCLE.	LOOP1 SPECIFY

Appendix B

MAXBAND OUTPUT ERROR MESSAGES.

The following error messages are produced by the Output module of MAXBAND if the maximization routine (MPCODE) does not find an optimal solution. They are preceded by the statement

```
MPCODE HAS TERMINATED WITH AN ERROR.
```

Many of these messages are similar to the messages produced by MPCODE on FORTRAN file 12. Land and Powell [1973] is useful for finding out more about these messages.

```
THE LINEAR PROGRAM SOLUTION IS UNBOUNDED.  CHECK THAT THE DATA HAS BEEN
    ENTERED PROPERLY.
```

Meaning: The current problem has no upper bound on the value of the objective function. This error should occur rarely if the data has been entered properly, and MAXBAND and MPCODE are executing properly. First check the data, and then Land and Powell [1973].

```
A LINEAR PROGRAM IS INSOLUBLE BECAUSE THERE IS NOT SUFFICIENT ROOM IN THE
    INVERSE MATRIX TO SOLVE IT (SEE INSTRUCTIONS).
```

Meaning: The dimensions of the matrix INV(142,142) and the other effective constraint matrices in MPCODE's blank common are too small. The value 142 should be sufficient for all but the very largest problems. If this error occurs, the dimensions of the matrices on line 3 of MPCODE's blank common should be increased, as described on page 190 of Land and Powell [1973], the MPCODE module should be recompiled, and the problem should be started again from the beginning (It cannot be restarted as explained in chapter 3 because no file is written to unit 7 in this case).

```
A LINEAR PROGRAM HAS EXCEEDED THE ALLOWED NUMBER OF ITERATIONS.  CHECK THE
    VALUE OF MAXITR.
```

Meaning: A linear program has performed more than MAXITR iterations. Reset MAXITR and start the problem again from the beginning (see the 'SETTING OPERATING PARAMETERS FOR MPCODE' section of chapter 3 for a discussion of MAXITR).

THE A MATRIX IS TOO BIG FOR THE SPACE ALLOCATED TO IT (SEE INSTRUCTIONS).

Meaning: The problem forumlation is too big to fit into MPCODE's A matrix. This can only happen if the user has modified the MAXBAND code to allow more intersections, without also altering the MPCODE program.

A LINEAR PROGRAM HAS EXCEED THE ALLOWED NUMBER OF REINVERSIONS. CHECK THE VALUE OF MAXINV.

Meaning: A linear program has performed more than MAXINV reinversions. Reset MAXINV and start the problem again from the beginning (see the 'SETTING OPERATING PARAMETERS FOR MPCODE' section of chapter 3 for a discussion of MAXINV).

THE LINEAR PROGRAM SOLUTION IS INFEASIBLE EVEN WITHOUT THE DISCRETE CONSTRAINTS. CHECK THAT THE DATA HAS BEEN ENTERED PROPERLY.

Meaning: The problem has no feasible solution. Check the data, particularly speed limits on links, to see that it has been entered properly.

THERE IS NO FEASIBLE DISCRETE SOLUTION TO THE PROBLEM AS ENTERED. CHECK THAT THE DATA HAS BEEN ENTERED PROPERLY.

Meaning: The problem has no feasible integer solution. Check the data, particularly speed limits on links, to see that it has been entered properly.

THE BRANCH AND BOUND ROUTINE HAS EXCEEDED THE ALLOWED NUMBER OF ITERATIONS. CHECK THE VALUE OF MAXRBB.

Meaning: The maximization routine has performed more than MAXRBB iterations, and the last linear program performed required more iterations than the number of constraints in the current formulation. Increase MAXRBB and start the problem again from the beginning (see the 'SETTING OPERATING PARAMETERS FOR MPCODE' section of chapter 3 for a discussion of MAXRBB).

This error differs from the last listed in this appendix, in that after completing the second to last linear program, MPCODE did not approach the limit of MAXRBB iterations closely enough before exceeding it to trigger the printing of a restart node.

THE BRANCH AND BOUND ROUTINE HAS EXCEEDED THE ALLOWED NUMBER OF REINVERSIONS. CHECK THE VALUE OF MAXIBB.

Meaning: The maximization routine has performed more than MAXIBB reinversions. Reset MAXIBB and start the problem again from the beginning (see the 'SETTING OPERATING PARAMETERS FOR MPCODE' section of chapter 3 for a discussion of MAXIBB).

THE BRANCH AND BOUND ROUTINE IS ABOUT TO EXCEED THE ALLOWED NUMBER OF ITERATIONS. A NODE HAS BEEN PUNCHED ON UNIT 7. TO RESTART, SET RESTRT TO 1 AND INPUT THE NODE FILE ON UNIT 8 (SEE INSTRUCTIONS).

Meaning: On completing the last linear program, the maximization routine has found that it is about to exceed MAXRBB iterations, so a restart node has been punched on file 7. The problem can be restarted as explained in the 'RESTARTING' section of chapter 3.

This differs from the third to last error listed in this appendix, in that MPCODE comes close to the limit of MAXRBB iterations, but does not exceed it, allowing a restart node to be punched.

Appendix C

MAXBAND INPUT FORMS.

The following forms may be used to gather data to be input on the MAXBAND input cards. The use of the forms is illustrated in chapter 4: MAXBAND Examples.

MAXBAND ARTERIAL INPUT

Basic Symmetric Case

Name of Artery: ______________________________________

Number of Signals: __________ Units (0-English,1-metric): ________ [1]

Signals entered from (N,S,E or W): ____________

Cycle time: Lower Limit: ____________ Upper Limit: ____________ seconds

Traffic speed (mph or kph):

Design speed: ______________________________

Tolerance: ______________________________ [2]

Limit on change between links: __________________ [3]

Inter.	Cross Street Name	Distance from previous intersection (feet or meters)	Main Street Green (cycles)
1.		XXXXXXXX	
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

Defaults: [1] 0-English
[2] 10% of design speed
[3] speed tolerance

MAXBAND ARTERIAL INPUT

Basic Asymmetric Case

Name of Artery: ____________________ Number of Signals: ________
Units (0-English,1-metric) ________ [1] Signals entered from (N,S,E or W): ________

Cycle times: Lower Limit: __________ Upper Limit: __________ seconds

Outbound speed (mph or kph):
Design speed: ______________
Tolerance: ______________ [2]
Limit on change between links: ______________ [3]

Inbound speed (mph or kph):
Design speed: ______________ [4]
Tolerance: ______________ [4]
Limit on change between links: ______________ [4]

Target ratio of inbound to outbound bandwidths (k): ______________ [5]
Objective function weights:
outbound (c(1)): ______________ [5] inbound (c(2)): ______________ [5]

Maximum number of MPCODE iterations (MAXRBB): ______________ [6]

Inter.	Cross Street Name	Distance from previous inter. (feet or meters)		Main Street Green Times (fractions of a cycle)				Left Patterns			
				outbound		inbound					
		outb.	inb.	through	left	through	left	1	2	3	4
1.		XXXX									
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											
11.											
12.											
13.											
14.											
15.											
16.											
17.											
18.											
19.											
20.											

Defaults:
[1] 0-English
[2] 10% of outbound design speed
[3] outbound speed tolerance
[4] outbound values
[5] 1
[6] 10000

MAXBAND ARTERIAL INPUT

p. 1

General Case

Name of Artery: ____________________ Number of Signals: __________
Units (0-English,1-metric) ________[1] Signals entered from (N,S,E or W): _______

Cycle times: Lower Limit: ___________ Upper Limit: ___________seconds

Outbound speed (mph or kph):
Design speed: _______________
Tolerance: _______________[2]
Limit on change between links: _______________[3]

Inbound speed (mph or kph):
Design speed: _______________ [4]
Tolerance: _______________ [4]
Limit on change between links: _______________ [4]

Target ratio of inbound to outbound bandwidths (k): _______________ [5]
Objective function weights:
outbound (c(1)): _______________[5] inbound (c(2)): _______________[5]

Maximum number of MPCODE iterations (MAXRBB): ______________________ [6]

Inter.	Cross Street Name	Distance from previous inter. (feet or meters)		Main Street Green Times (fractions of a cycle)				Left Patterns			
				outbound		inbound					
		outb.	inb.	through	left	through	left	1	2	3	4
1.		XXXX									
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											
11.											
12.											
13.											
14.											
15.											
16.											
17.											
18.											
19.											
20.											

Defaults:
[1] 0-English
[2] 10% of outbound design speed
[3] outbound speed tolerance
[4] outbound values
[5] 1
[6] 10000

General Case

Traffic Volumes in vehicles per hour

Inter.	NB through	NB left	SB through	SB left	EB through	EB left	WB through	WB left
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								

Traffic Capacities in vehicles per hour

Inter.	NB through	NB left	SB through	SB left	EB through	EB left	WB through	WB left
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								

MAXBAND ARTERIAL INPUT

General Case

Minimum Green Times in fractions of a cycle

Inter.	NB		SB		EB		WB	
	through	left	through	left	through	left	through	left
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								

Inter.	Speed values on Specific Signal Approaches (mph or kph)				Bandwidth Advance (Queue Clear times) (cycles)	
	outbound		inbound			
	speed	toler.	speed	toler.	outbound	inbound
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						

MAXBAND LOOP INPUT

Name of loop: ____________________ Number of Signals: ____________

Cycle times: Lower Limit: __________ Upper Limit: __________ seconds

Loop geometry:

Arteries 1 and 2 meet at signal _______ in artery 1
and signal _______ in artery 2

Arteries 1 and 3 meet at signal _______ in artery 1
and signal _______ in artery 3

Arteries 2 and 3 meet at signal _______ in artery 2
and signal _______ in artery 3

Target ratios of outbound bandwidths:

Artery 2 to 1 (k(4)): __________ [1]
Artery 3 to 1 (k(5)): __________ [1]
Artery 3 to 2 (k(6)): __________ [1]

Maximum number of MPCODE iterations (MAXRBB): _______________ [2]

Information about the three arteries is entered on individual MAXBAND ARTERIAL INPUT forms.

Defaults: [1] 0
[2] 10000

Appendix D

MAXBAND'S INTERNAL SPLIT MODEL AND THE SPLIT DERIVATION PROCESS.

This appendix presents the details of MAXBAND's split model, and explains the process by which MAXBAND derives the splits used in the problem formulation.

D.1 MAXBAND'S INTERNAL SPLIT MODEL.

MAXBAND uses the model of cycle division shown in figure 60. This figure shows how the cycle might be divided for a signal on an artery entered from the south. By changing the directional labels of the figure in the obvious manner, corresponding figures can be obtained for arteries entered from other directions. The important features of this model are:

1. The cycle is divided into a main street phase and a cross street phase. In addition, there maybe all red phases between the main and cross street phases during which all traffic movements have a red light.

2. For each direction on the main street, the main street phase is divided into a green phase and a red phase. For each direction, the red phase is a period during which the other direction may make left turns. Hence the length of the red phase of the main street phase for each direction is considered to be the left green split of the opposite direction, l(in) or l(out), where 'out' and 'in' refer to the outbound and inbound directions. Note that the left splits l(out) and l(in) represent the maximum time available for making protected left turns. The user may choose to have protected left turn times which are less than l(out) and l(in). In turn, the length of the green phase is considered to be the through green split in its direction, g(in) or g(out). Note that the red split in each direction is the sum of the lengths of the red portion of the main street phase in its direction, the cross street phase, and any all red periods.

   Note that, in figure 60, the points of division between the SB through and NB left phases, and between the NB through and SB left phases, of the main street phase, represent an arbitrary example of split allocation. The division of the main street phase for an actual signal need not be the same.

3. Though MAXBAND is primarily concerned with splits on the main street, the cross street phase can be divided into outbound and inbound, through and left, green splits in the same way.

   Similarly to point 2, note that the particular division of the cross street phase between through and left splits shown in figure 60 is an example only. The division of the phase can be different for each real intersection.

4. The model requires that the length of the main street phase be the same in both directions. Hence, the sums of the green and red periods of the main street phase in each direction must be the same. Since each direction may make protected left turns during the red period of the opposite direction, MAXBAND makes the left turn splits, l(out) and l(in), equal to the lengths of the red periods of the main street phase in the opposite direction, thereby including all of this potential protected left turn time in its formulation. Hence, the equal sum requirement above can be restated as

$$g(out) + l(in) = g(in) + l(out)$$

   The user may later decide to use only some of this protected left time when assigning actual left splits. For example, by making the actual outbound left split shorter than l(out), or the actual inbound left split shorter than l(in), the user can have both left splits leading, but beginning at different times, or both left splits lagging, but ending at different times.

5. The overall effect of features 1 and 4 is that MAXBAND divides the cycle into two periods:

   a) The main street phase (part A of the cycle in figure 60), in which both main street directions are going through or turning left; and

   b) The cross street phase and all red phases (part B of the cycle in figure 60), during which neither direction is going through or turning left.

   The portion of the cycle not used by the main street, that is, the cross street phase and any all red periods (part B of the cycle in figure 60) is called the 'cross street core time'.

6. MAXBAND allows the red portion of the main street phase in each direction to be placed at either the beginning or the end of the main street phase. Since the red portion corresponds to a left turn period for the opposite direction, there are four patterns of left turns available on the main street. These are explained in detail in the 'Choosing a left turn pattern' subsection of chapter 3.

Signals entered from South

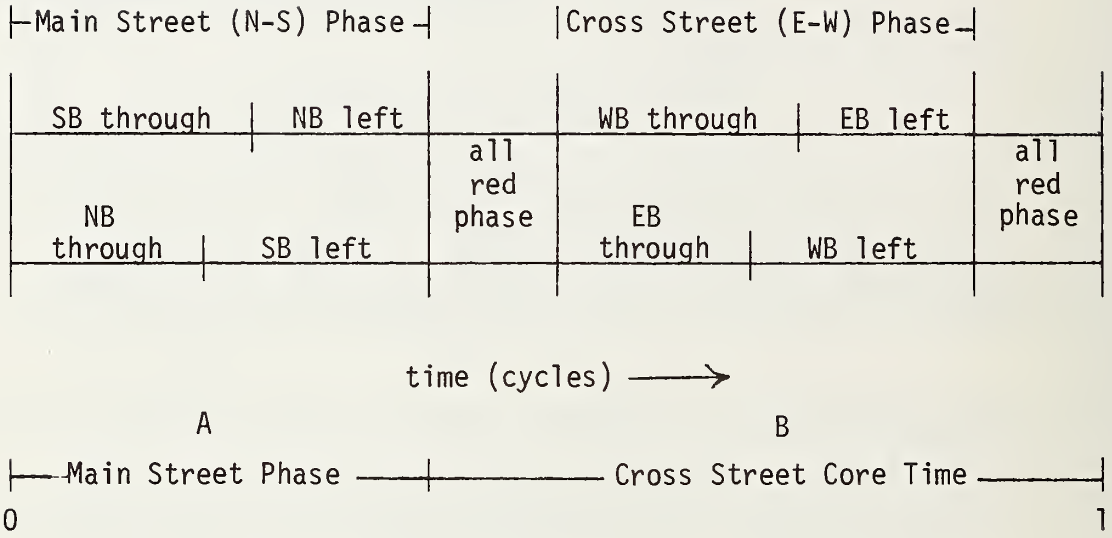


Figure 60: MAXBAND's internal split model.

D.2 HOW MAXBAND DERIVES SPLITS.

Figure 61 shows the procedure by which MAXBAND derives the splits used in the problem formulation. The steps are

1. Preliminary splits are obtained from the SPECIFY card, if it is present. Otherwise, preliminary splits are computed from the values entered on the VOLUME and SPECIFY cards.

2. The preliminary splits are modified so that the minimum split length requirements entered on the MINGREEN card are satisfied. If this card is not present and the preliminary splits have been computed from volume and capacity information, MAXBAND will use default minimum green times to modify the splits.

3. The modified splits are adjusted so that the MAXBAND formulation contains the maximum protected left turn time available, and so that one direction of the main street is not completely stopped while the other is able to go through or make left turns. This insures that the cycle can be divided into the main street phase and the cross street core time. This is done by making the main street phase in each direction the same length. If necessary, this takes the form of lengthening the left turn split of one of the main street directions.

These steps are explained in greater detail below.

The splits obtained after these three steps have been performed are those printed in the 'Input Data Summary' section of the output and used in the formulation of the problem passed to MPCODE.

D.2.1 Obtaining splits.

MAXBAND allows the user to enter each of the nine signal and approach specific (group 5) cards once for each intersection. It is required that either the SPECIFY card or both the VOLUME and CAPACITY cards be among those entered.

D.2.1.1 Obtaining splits from the SPECIFY card.

If the SPECIFY card is present, the split values on it are used in stage 1 of figure 61, and the VOLUME and CAPACITY cards are ignored for the purpose of obtaining splits.

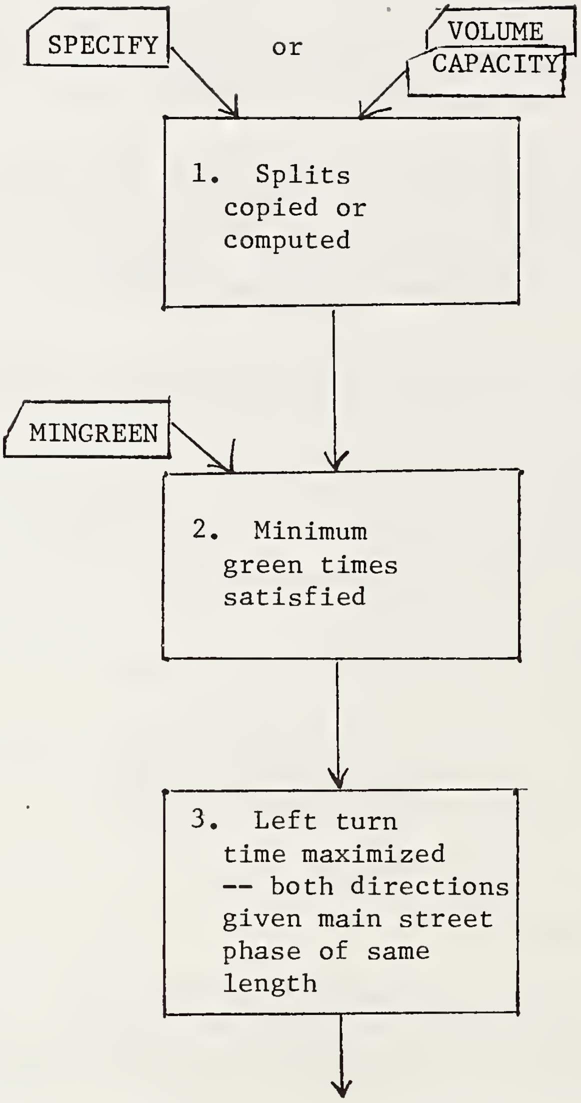

SPECIFY
or
VOLUME
CAPACITY
1. Splits copied or computed
MINGREEN
2. Minimum green times satisfied
3. Left turn time maximized -- both directions given main street phase of same length

Figure 61: Procedure for determining splits.

D.2.1.2 Computing splits from values on the VOLUME and CAPACITY cards.

If the SPECIFY card is not present, the splits used in stage 1 are computed from the values on the VOLUME and CAPACITY cards.

Split calculation is a modified form of the Webster method.

The procedure is illustrated in figure 62. The steps are

1. The ratio of volume to capacity is calculated for each of the eight turning movements at the intersection. The eight movements correspond to the eight fields on the SPECIFY, VOLUME, CAPACITY and MINGREEN cards. These movements are

   northbound through and left
   southbound through and left
   eastbound through and left
   westbound through and left

   If any movement has a capacity of zero, its ratio is set to zero.

2. The cycle is apportioned between the main and cross streets by comparing these ratios.

3. The main street phase is divided into outbound and inbound through and left splits by again using the ratios.

When splits are computed, the internal division of the cross street core time is not considered, except to determine how long this core time needs to be.

The model of splits and cycle division actually used when splits are computed is shown in figure 63.

The equations used in the first step have the form

$$\mathrm{TRAT}(i) = \begin{cases} \mathrm{TVOL}(i) / \mathrm{TCAP}(i) & \text{if } \mathrm{TCAP}(i) > 0 \\ 0 & \text{if } \mathrm{TCAP}(i) = 0 \end{cases}$$

and

$$\mathrm{LRAT}(i) = \begin{cases} \mathrm{LVOL}(i) / \mathrm{LCAP}(i) & \text{if } \mathrm{LCAP}(i) > 0 \\ 0 & \text{if } \mathrm{LCAP}(i) = 0 \end{cases}$$

where TRAT(i) is the ratio of through volume to capacity in direction i,
LRAT(i) is the ratio of left volume to capacity in direction i,
TVOL(i) is the through volume in direction i,
LVOL(i) is the left volume in direction i,
TCAP(i) is the through capacity in direction i, and
LCAP(i) is the left capacity in direction i.

Signals entered from south

* fields used on VOLUME and CAPACITY cards

1 8	15	20	25	30	35	40	45	50	55	56	65 80
		*	*	*	*	*	*	*	*		
VOLUME		656	49	501	204	1471	220	912	38		
CAPACITY		2000	1000	2000	1000	2000	1000	2000	1000		
		T	L	T	L	T	L	T	L		
		NB		SB		EB		WB			

T - through
L - left

Step 1:	TRAT (N)	LRAT (N)	TRAT (S)	LRAT (S)	TRAT (E)	LRAT (E)	TRAT (W)	LRAT (W)
ratios:	.328	.049	.2505	.204	.7355	.220	.456	.038

Step 2:

maximum main street ratio sum: maximum (.328+.204,.049+.2505)
= .532

maximum cross street ratio sum: maximum (.7355+.038,.220+.456)
= .7735

Hence B(cross street core time)= $\frac{.7735}{.532+.7735} = .5925$

A(main street phase) $= .4075$

Step 3:

NB through $= \frac{.328}{.328 + .204} \times .4075 = .2512$

SB left $= \frac{.204}{.328 + .204} \times .4075 = .1563$

SB through $= \frac{.2505}{.2505+.049} \times .4075 = .3408$

NB left $= \frac{.049}{.2505+.049} \times .4075 = .0667$

Figure 62: A sample split calculation.

In the second step, dividing the cycle between the main and cross street, MAXBAND first finds the quantities

$$\text{MAIN} = \text{maximum}\ (\text{TRAT(OUT)}+\text{LRAT(IN)},\text{TRAT(IN)}+\text{LRAT(OUT)})$$
$$\text{CROSS} = \text{maximum}\ (\text{TRAT}(i)+\text{LRAT}(j),\text{TRAT}(j)+\text{LRAT}(i))$$

where OUT is the outbound direction on the main street
IN is the inbound direction on the main street
and i and j are the two direction on the cross street.

The cross street core time (portion B of the cycle in figure 63) is then

$$\text{CORE} = \frac{\text{CROSS}}{\text{MAIN} + \text{CROSS}}$$

Note that the sum MAIN + CROSS cannot be zero because of restrictions on the data entered on the VOLUME and CAPACITY cards.

In the third step, having obtained the portion of the cycle to be allocated to the main street from the second step, specific splits are computed using the main street ratios from the first step:

$$l(\text{out}) = \frac{\text{LRAT(out)}}{\text{TRAT(out)} + \text{LRAT(in)}} \times (1 - \text{CORE})$$

and

$$l(\text{in}) = \frac{\text{LRAT(in)}}{\text{TRAT(in)} + \text{LRAT(out)}} \times (1 - \text{CORE})$$

$$g(\text{out}) = 1 - \text{CORE} - l(\text{in})$$

and

$$g(\text{in}) = 1 - \text{CORE} - l(\text{out})$$

where l(out) is the outbound left split,
l(in) is the inbound left split,
g(out) is the outbound through split, and
g(in) is the inbound through split.

If the main street is a one-way street, it is possible that one of the sums TRAT(OUT) + LRAT(IN) or TRAT(IN) + LRAT(OUT) is zero. In the former case, the outbound through and inbound left splits are set to zero. In the latter case, the inbound through and outbound left splits are set to zero.

D.2.2 Modifying splits to conform with minimum split times.

The MINGREEN card is used to specify minimum lengths for the splits associated with all eight movements at a intersection. The main street minimums will be applied directly to the main street splits, while the cross street minimums are used to determine the minimum length required for the cross street core time (portion B of the cycle in figure 63).

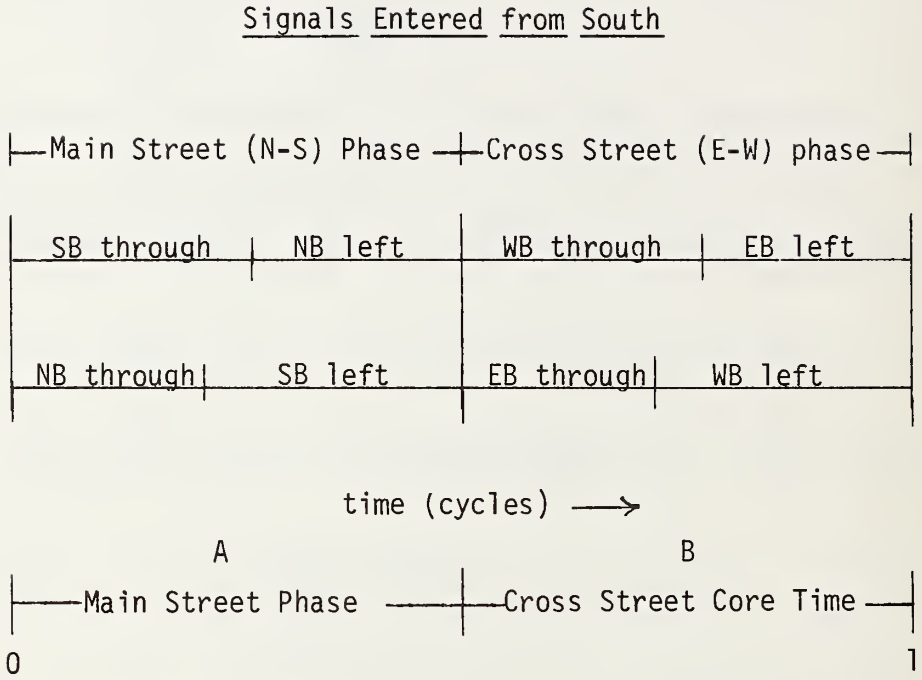


Figure 63: Split model used when splits are calculated.

Figure 64 shows the minimum green logic. If a MINGREEN card is present, the values on it are used to modify the splits. This is true regardless of whether the splits were taken directly from the SPECIFY card or computed from VOLUME and CAPACITY card information in stage 1 of figure 61. If there is no MINGREEN card, and splits were given on the SPECIFY card, the splits are not changed at this point. If, however, there is no MINGREEN card and splits were computed from VOLUME and CAPACITY card information, MAXBAND will use default minimum split times, as explained below.

If a MINGREEN card is present, MAXBAND performs the following (see figure 65):

1. The main street splits g(out), g(in), l(out), and l(in) are increased until they at least equal the minimum times given. If a split exceeds its minimum before being increased, it is not changed. The revised splits so obtained are referred to below as gnew(out), gnew(in), lnew(out), and lnew(in).

2. The minimum portion of the cycle to be allocated to the cross street core time, MCORE, is computed as

   $$\text{MCORE} = \text{maximum}\ (\text{TMIN}(i)+\text{LMIN}(j),\text{TMIN}(j)+\text{LMIN}(i))$$

   where i and j are the cross street directions,
     and TMIN(i) is the minimum through split in direction i,
     and LMIN(i) is the minimum left split in direction i.

3. The revised outbound through split, gnew(out), and inbound left split, lnew(in), are added to MCORE. Figure 63 requires that the sum be less than or equal to one. If this is true, steps 4. and 5. are skipped.

4. If the sum gnew(out) + lnew(in) + MCORE is greater than one, MAXBAND compresses the main street splits. It does this by computing new values for gnew(out) and lnew(in):

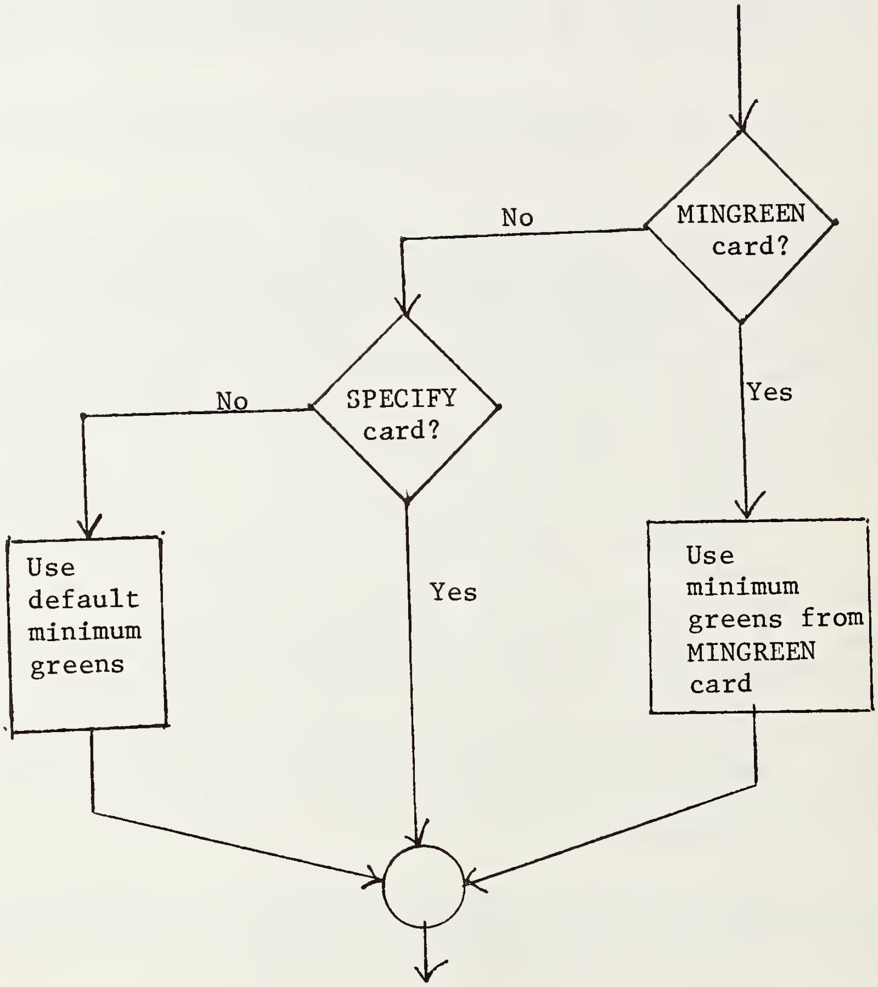
   $$\text{gnew(out)} = \frac{\text{g(out)}}{\text{g(out)} + \text{l(in)}} \times (1 - \text{MCORE})$$

   and

   $$\text{lnew(in)} = \frac{\text{l(in)}}{\text{g(out)} + \text{l(in)}} \times (1 - \text{MCORE})$$

5. If gnew(out) is less than the minimum outbound through split, TMIN(out), gnew(out) is set to TMIN(out) and lnew(in) is set to 1 - MCORE - TMIN(out), and the rest of this point is skipped.

   Otherwise, lnew(in) is checked to see that it has some minimum value. In order to prevent positive inbound left splits



MINGREEN card?
No
Yes
SPECIFY card?
No
Yes
Use default minimum greens
Use minimum greens from MINGREEN card

Figure 64: Minimum green logic.

from becoming too small, MAXBAND computes a new value to be used as this minimum, called LBRMIN, as follows:

$$\text{If } l(in) = 0 \text{ or } LMIN(in) > 0, \quad LBRMIN = LMIN(in)$$

otherwise

$$LBRMIN = \text{minimum } (0.05,\ 1-TMIN(out)-MCORE,\ l(in))$$

Then if lnew(in) is less than LBRMIN, lnew(in) is set to LBRMIN and gnew(out) is set to 1 - MCORE - LBRMIN.

Hence, if MAXBAND is compressing the main street splits, and the original value of the inbound left split, l(in), is greater than zero, but the user has specified a minimum of zero for this split, MAXBAND will attempt to prevent the inbound left split from becoming to small. It does this by

a) Making the minimum for the split 0.05 if the original inbound left split (l(in)) is greater than 0.05, and at least this much of the cycle is not taken by the minimum outbound through split and the minimum cross street core time.

b) Making the minimum for the split its original value (l(in)), if this value is less than 0.05, and at least this much of the cycle is not taken by the minimum outbound through split and the minimum cross street core time.

c) Making the minimum for the split the portion of the cycle not taken by the minimum outbound through split and the minimum cross street core time, if this value is less than both 0.05 and the original value of the inbound left split (l(in)).

Note that because it is required on entry of the MINGREEN card that

$$TMIN(out) + LMIN(in) + MCORE \leq 1$$

steps 4. and 5. will always lead to a set of splits gnew(out) and lnew(in) such that

$$gnew(out) + lnew(in) + MCORE \leq 1$$

6. g(out) is set to gnew(out) and l(in) is set to lnew(in). These values for g(out) and l(in) will be passed to the third step of the split derivation process shown in figure 61.

7. Steps 3. through 6. are repeated for g(in) and l(out) (using, in additon, gnew(in) and lnew(out)).

If a MINGREEN card is not present and splits were computed from VOLUME and CAPACITY card information, each of g(out), g(in), l(out), and l(in) is set to 0.05 if

Signals entered from south

* field used on MINGREEN card

1 8	15	*20	*25	*30	*35	*40	*45	*50	*55	56	65 80
MINGREEN		0	0	0	0	.5	0	.5	0		
		T	L	T	L	T	L	T	L		
		NB		SB		EB		WB			

Original .50 .03 .60 .13 - - - -
splits (from stage 1 of split derivation process)

Step 1: splits expanded by MINGREEN values:

.50 .03 .60 .13

Step 2: MCORE =

maximum (.5+0,.5+0) = .5

Steps 3 and 4: Here out is NB and in is SB

$$\text{gnew(out)} + \text{lnew(in)} + \text{MCORE} = .50 + .13 + .5 = 1.13 > 1$$

$$\text{so} \quad \text{gnew(out)} = \frac{.50}{.50 + .13} \times (1 - .50) = .3975$$

$$\text{lnew(in)} = \frac{.13}{.50 + .13} \times (1 - .50) = .1025$$

$$\text{and gnew(in)} + \text{lnew(out)} + \text{MCORE} = .60 + .03 + .5 = 1.13 > 1$$

$$\text{so} \quad \text{gnew(in)} = \frac{.60}{.60 + .03} \times (1 - .50) = .4762$$

$$\text{lnew(out)} = \frac{.03}{.60 + .03} \times (1 - .50) = .0238$$

Step 5:

$$\left\{\begin{array}{l} \text{gnew(out)} = .3975 > 0 = \text{tmin(out)} \\ \text{lnew(in)} = .1025 > 0.05 = \min(1 - .5 - 0,\ 0.05,\ .13) \end{array}\right.$$

$$\text{but} \left\{\begin{array}{l} \text{gnew(in)} = .4762 > 0 = \text{tmin(in)} \\ \text{lnew(out)} = .0238 < 0.03 = \min(1 - .5 - 0,\ 0.05,\ 0.03) \end{array}\right.$$

$$\text{so} \quad \text{lnew(out)} = 0.03$$

$$\text{gnew(in)} = 0.47$$

Step 6: The splits passed to stage 3 of the split derivation process are:

NB		SB	
T	L	T	L
.3975	0.03	.47	.1025

Figure 65: Modifying splits according to minimum values.

1. it is less than 0.05, and

2. the capacity of the corresponding movement is greater than zero.

D.2.3 Using all left turn time and setting up main street phase and cross street core time.

Having obtained main street splits, and having modified them according to the values on the MINGREEN card or default minimums, MAXBAND adjusts the splits so that one direction of the main street is not completely stopped while the other is able to go through or turn left. In this way, it insures that the cycle can be divided into the main street phase and the cross street core time, as required by the split model shown in figures 60 and 63. It does this by making the main street phase the same length in each direction, by comparing the sums

$$g(out) + l(in)$$

and

$$g(in) + l(out)$$

If these sums are not equal, the left split of the smaller sum is increased until they are.

This insures that the left turn splits used in the formulation represent the greatest amount of protected left turn time available. The user may choose to use smaller left splits later if desired. By shortening one of the splits, it would be possible to have both left turns leading, but starting at different times, or both left turns lagging, but ending at different times.

Appendix E

SAMPLE OUTPUTS.

This appendix contains the output produced by examples 2 and 3 of chapter 4.

1. The Waltham artery.

2. The Voorhees example artery.

```
                    **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****

                                        **** MAXBAND INPUT CARDS ****

START         0    0
MPCODE         10000  100 1000  100    0
SETUP             11                   0               S       WALTHAM
ARTERY       60  100                        1   11
ART2          1    1    1   20    2    2   20    2    2
MAP              101    1                                      BANKS
SPECIFY        .6875.1500.5375    0
LENGTH
LEFTPAT       1    1
MAP              102    2                                      PROSPECT
SPECIFY        .4375     .4375
LENGTH           810
MAP              103    3                                      BACON
SPECIFY        .7125.1375.5750    0
LENGTH          1105
LEFTPAT       1    1
MAP              104    4                                      EXCHANGE
SPECIFY        .7500     .7500
LENGTH           755
MAP              105    5                                      MOODY
SPECIFY        .3250     .3250
LENGTH           800
MAP              106    6                                      LEXINGTON
SPECIFY        .6625.2750.3875    0
LENGTH           360
LEFTPAT       1    1
MAP              107    7                                      ELM
SPECIFY        .6625.2750.3875    0
LENGTH           230
LEFTPAT       1    1
MAP              108    8                                      APPLETON
SPECIFY        .7500     .7500
LENGTH           830
MAP              109    9                                      LYMAN
SPECIFY        .5875     .5875
LENGTH           410
MAP              110   10                                      NEWTON
SPECIFY        .4625     .4625
LENGTH           340
MAP              111   11                                      LINDEN
SPECIFY        .6500.2000.4500    0
LENGTH          1050
LEFTPAT       1    1
END
```

```
DATA HAS BEEN SUCCESSFULLY ENTERED.
```

```
                              **** MAXBAND INPUT DATA SUMMARY ****

                                        MPCODE VALUES

MAXIMUM BRANCH AND BOUND ITERATIONS (MAXRBB):      10000     MAXIMUM BRANCH AND BOUND REINVERSIONS (MAXIBB):   100
MAXIMUM LINEAR PROGRAM ITERATIONS (MAXITR):  1000    MAXIMUM LINEAR PROGRAM REINVERSIONS (MAXINV):   100
RESTART: 0     (0 -- JOB IS NOT A RESTART; 1 -- JOB IS A RESTART)


THIS IS AN ARTERY PROBLEM.

NAME OF ARTERY: WALTHAM              NUMBER OF INTERSECTIONS: 11
LOWER CYCLE LIMIT:  60.00     SECS     UPPER CYCLE LIMIT:  100.0     SECS

ARTERY IS ENTERED FROM: SOUTH     UNITS: ENGLISH
                                                                             SOURCE *
TARGET BANDWIDTH RATIO SOUTHBOUND TO NORTHBOUND (K):          1.000            0
WEIGHT OF NORTHBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(1)):  1.000            0
WEIGHT OF SOUTHBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(2)):  1.000            0
                                                     * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)


                                                      ARTERY WIDE VALUES
                                                                NORTHBOUND          SOUTHBOUND

               DESIGN SPEED (MILES/HOUR):                         20.00               20.00
               TOLERANCES (MILES/HOUR):                           2.000               2.000
               CHANGES BETWEEN LINKS (MILES/HOUR):                2.000               2.000
```

```
                                                         INTERSECTION VALUES
                                                                 NORTHBOUND                                    SOUTHBOUND

                     LEFT                        SPLITS   - - - - SPLITS - - - -         QUEUE      - - - - SPLITS - - - -         QUEUE
SIGNAL  NODE  SEQ.  CHOICES      CROSS STREET    SOURCE    GREEN     LEFT      RED     CLEARANCE     GREEN     LEFT      RED     CLEARANCE
  NO.    NO.   NO.   1234 +          NAME           *     - - - (FRACTIONS OF A CYCLE) - - -        - - - (FRACTIONS OF A CYCLE) - - -

   1     101    1    1100    BANKS                  0     0.6875    0.1500    0.3125    0.0          0.5375    0.0       0.4625    0.0

   2     102    2    0000    PROSPECT               0     0.4375    0.0       0.5625    0.0          0.4375    0.0       0.5625    0.0

   3     103    3    1100    BACON                  0     0.7125    0.1375    0.2875    0.0          0.5750    0.0       0.4250    0.0

   4     104    4    0000    EXCHANGE               0     0.7500    0.0       0.2500    0.0          0.7500    0.0       0.2500    0.0

   5     105    5    0000    MOODY                  0     0.3250    0.0       0.6750    0.0          0.3250    0.0       0.6750    0.0

   6     106    6    1100    LEXINGTON              0     0.6625    0.2750    0.3375    0.0          0.3875    0.0       0.6125    0.0

   7     107    7    1100    ELM                    0     0.6625    0.2750    0.3375    0.0          0.3875    0.0       0.6125    0.0

   8     108    8    0000    APPLETON               0     0.7500    0.0       0.2500    0.0          0.7500    0.0       0.2500    0.0

   9     109    9    0000    LYMAN                  0     0.5875    0.0       0.4125    0.0          0.5875    0.0       0.4125    0.0

  10     110   10    0000    NEWTON                 0     0.4625    0.0       0.5375    0.0          0.4625    0.0       0.5375    0.0

  11     111   11    1100    LINDEN                 0     0.6500    0.2000    0.3500    0.0          0.4500    0.0       0.5500    0.0

                          * (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

             NOTE:  THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

                                        + (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

                                   PATTERN 1 -- NORTHBOUND LEFT LEADS GREEN; SOUTHBOUND LEFT  LAGS GREEN
                                   PATTERN 2 -- NORTHBOUND LEFT  LAGS GREEN; SOUTHBOUND LEFT LEADS GREEN
                                   PATTERN 3 -- NORTHBOUND LEFT LEADS GREEN; SOUTHBOUND LEFT LEADS GREEN
                                   PATTERN 4 -- NORTHBOUND LEFT  LAGS GREEN; SOUTHBOUND LEFT  LAGS GREEN

                                                -- NO MINIMUM GREEN TIMES GIVEN --
```

```
                                              LINK VALUES
                              NORTHBOUND                                  SOUTHBOUND

SIGNAL                LENGTH      SPEED       TOLERANCE      LENGTH       SPEED       TOLERANCE
 NO.                  (FEET)  (MILES/HOUR) (MILES/HOUR)      (FEET)   (MILES/HOUR) (MILES/HOUR)

  1
       --------      810.000     20.000       2.0000        810.000     20.000       2.0000
  2
       --------      1105.00     20.000       2.0000        1105.00     20.000       2.0000
  3
       --------      755.000     20.000       2.0000        755.000     20.000       2.0000
  4
       --------      800.000     20.000       2.0000        800.000     20.000       2.0000
  5
       --------      360.000     20.000       2.0000        360.000     20.000       2.0000
  6
       --------      230.000     20.000       2.0000        230.000     20.000       2.0000
  7
       --------      830.000     20.000       2.0000        830.000     20.000       2.0000
  8
       --------      410.000     20.000       2.0000        410.000     20.000       2.0000
  9
       --------      340.000     20.000       2.0000        340.000     20.000       2.0000
 10
       --------      1050.00     20.000       2.0000        1050.00     20.000       2.0000
 11

                                     -- NO VOLUMES GIVEN --

                                    -- NO CAPACITIES GIVEN --
```

```
MPCODE HAS SUCCESSFULLY COMPLETED.
 A REPORT BASED ON THE OPTIMAL SOLUTION WILL BE WRITTEN.


                                        **** MPCODE STATISTICS ****

   NUMBER OF BRANCH AND BOUND ITERATIONS PERFORMED:       3781     NUMBER OF BRANCH AND BOUND REINVERSIONS PERFORMED:

   MAXIMUM NUMBER OF ITERATIONS PERFORMED BY A LINEAR PROGRAM:    90
   MAXIMUM NUMBER OF REINVERSIONS PERFORMED BY A LINEAR PROGRAM:    1

   NUMBER OF SOLUTIONS FOUND:   7     VALUE OF OBJECTIVE FUNCTION AT LAST SOLUTION:  .578077
```

```
                              **** MAXBAND SOLUTION REPORT ****

THIS IS AN ARTERY PROBLEM.

NAME OF ARTERY: WALTHAM              NUMBER OF INTERSECTIONS: 11
ARTERY IS ENTERED FROM: SOUTH     UNITS: ENGLISH

                                        **** BEST SOLUTION ****

CYCLE TIME:  65.25     SECS     NORTHBOUND BANDWIDTH (B(1)): 0.2890     SOUTHBOUND BANDWIDTH (B(2)): 0.2890
                                           (FRACTION OF A CYCLE)                    (FRACTION OF A CYCLE)

OBJECTIVE FUNCTION (C(1)B(1) + C(2)B(2)):  .578077

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE NORTHBOUND DIRECTION AT SIGNAL 1.


                                        INTERSECTION INFORMATION

                        SIGNAL    NODE   SEQUENCE   CROSS STREET   LEFT TURN PATTERN
                          NO.      NO.      NO.         NAME           SELECTED

                          1       101       1      BANKS                  2

                          2       102       2      PROSPECT

                          3       103       3      BACON                  1

                          4       104       4      EXCHANGE

                          5       105       5      MOODY

                          6       106       6      LEXINGTON              2

                          7       107       7      ELM                    1

                          8       108       8      APPLETON

                          9       109       9      LYMAN

                         10       110      10      NEWTON

                         11       111      11      LINDEN                 2
```

```
                                        PHASE SETTINGS -- FRACTIONS OF A CYCLE

                      - - - - GREEN - - - -      - - - - LEFT  - - - -      - - - -  RED  - - - -      - - - - - - - BAND - - - - - - -
SIGNAL                                                                                                                          ADVANCED BY
  NO.   DIRECTION     BEGIN    END  DURATION    BEGIN    END  DURATION    BEGIN    END  DURATION    BEGIN    END  DURATION  QUEUE CLEAR
                                                                                                                                  TIME

   1    NORTHBOUND    .0      .6875  0.6875     .5375   .6875  0.1500     .6875   .0      0.3125     .2506   .5396  0.2890      0.0
        SOUTHBOUND    .0      .5375  0.5375                    0.0        .5375   .0      0.4625     .0      .2890  0.2890      0.0

   2    NORTHBOUND    .5682   .0057  0.4375                    0.0        .0057   .5682   0.5625     .6353   .9244  0.2890      0.0
        SOUTHBOUND    .5682   .0057  0.4375                    0.0        .0057   .5682   0.5625     .5682   .8573  0.2890      0.0

   3    NORTHBOUND    .7892   .5017  0.7125     .7892   .9267  0.1375     .5017   .7892   0.2875     .2127   .5017  0.2890      0.0
        SOUTHBOUND    .9267   .5017  0.5750                    0.0        .5017   .9267   0.4250     .9267   .2157  0.2890      0.0

   4    NORTHBOUND    .4897   .2397  0.7500                    0.0        .2397   .4897   0.2500     .5713   .8603  0.2890      0.0
        SOUTHBOUND    .4897   .2397  0.7500                    0.0        .2397   .4897   0.2500     .4897   .7787  0.2890      0.0

   5    NORTHBOUND    .9893   .3143  0.3250                    0.0        .3143   .9893   0.6750     .9893   .2783  0.2890      0.0
        SOUTHBOUND    .9893   .3143  0.3250                    0.0        .3143   .9893   0.6750     .0253   .3143  0.2890      0.0

   6    NORTHBOUND    .8172   .4797  0.6625     .2047   .4797  0.2750     .4797   .8172   0.3375     .1907   .4797  0.2890      0.0
        SOUTHBOUND    .8172   .2047  0.3875                    0.0        .2047   .8172   0.6125     .8172   .1063  0.2890      0.0

   7    NORTHBOUND    .3218   .9843  0.6625     .3218   .5968  0.2750     .9843   .3218   0.3375     .3218   .6108  0.2890      0.0
        SOUTHBOUND    .5968   .9843  0.3875                    0.0        .9843   .5968   0.6125     .6953   .9843  0.2890      0.0

   8    NORTHBOUND    .2945   .0445  0.7500                    0.0        .0445   .2945   0.2500     .7555   .0445  0.2890      0.0
        SOUTHBOUND    .2945   .0445  0.7500                    0.0        .0445   .2945   0.2500     .2945   .5835  0.2890      0.0

   9    NORTHBOUND    .8013   .3888  0.5875                    0.0        .3888   .8013   0.4125     .9502   .2393  0.2890      0.0
        SOUTHBOUND    .8013   .3888  0.5875                    0.0        .3888   .8013   0.4125     .0998   .3888  0.2890      0.0

  10    NORTHBOUND    .9383   .4008  0.4625                    0.0        .4008   .9383   0.5375     .1117   .4008  0.2890      0.0
        SOUTHBOUND    .9383   .4008  0.4625                    0.0        .4008   .9383   0.5375     .9383   .2273  0.2890      0.0
```

```
                                              PHASE SETTINGS -- FRACTIONS OF A CYCLE

                           - - - - GREEN - - - -     - - - - LEFT - - - -     - - - - RED - - - -     - - - - - - - BAND - - - - - - -
SIGNAL                                                                                                                       ADVANCED BY
 NO.    DIRECTION          BEGIN    END  DURATION    BEGIN    END  DURATION    BEGIN    END  DURATION    BEGIN    END  DURATION  QUEUE CLEAR
                                                                                                                                TIME

 11    NORTHBOUND          .3896   .0396  0.6500     .8396   .0396  0.2000     .0396   .3896  0.3500     .6105   .8995  0.2890     0.0
       SOUTHBOUND          .3896   .8396  0.4500                    0.0        .8396.  .3896  0.5500     .3896   .6787  0.2890     0.0
```

PHASE SETTINGS -- SECONDS

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	BAND ADVANCED BY QUEUE CLEAR TIME
1	NORTHBOUND	0.0	44.9	44.9	35.1	44.9	9.8	44.9	0.0	20.4	16.3	35.2	18.9	0.0
	SOUTHBOUND	0.0	35.1	35.1			0.0	35.1	0.0	30.2	0.0	18.9	18.9	0.0
2	NORTHBOUND	37.1	0.4	28.5			0.0	0.4	37.1	36.7	41.5	60.3	18.9	0.0
	SOUTHBOUND	37.1	0.4	28.5			0.0	0.4	37.1	36.7	37.1	55.9	18.9	0.0
3	NORTHBOUND	51.5	32.7	46.5	51.5	60.5	9.0	32.7	51.5	18.8	13.9	32.7	18.9	0.0
	SOUTHBOUND	60.5	32.7	37.5			0.0	32.7	60.5	27.7	60.5	14.1	18.9	0.0
4	NORTHBOUND	32.0	15.6	48.9			0.0	15.6	32.0	16.3	37.3	56.1	18.9	0.0
	SOUTHBOUND	32.0	15.6	48.9			0.0	15.6	32.0	16.3	32.0	50.8	18.9	0.0
5	NORTHBOUND	64.5	20.5	21.2			0.0	20.5	64.5	44.0	64.5	18.2	18.9	0.0
	SOUTHBOUND	64.5	20.5	21.2			0.0	20.5	64.5	44.0	1.6	20.5	18.9	0.0
6	NORTHBOUND	53.3	31.3	43.2	13.4	31.3	17.9	31.3	53.3	22.0	12.4	31.3	18.9	0.0
	SOUTHBOUND	53.3	13.4	25.3			0.0	13.4	53.3	40.0	53.3	6.9	18.9	0.0
7	NORTHBOUND	21.0	64.2	43.2	21.0	38.9	17.9	64.2	21.0	22.0	21.0	39.9	18.9	0.0
	SOUTHBOUND	38.9	64.2	25.3			0.0	64.2	38.9	40.0	45.4	64.2	18.9	0.0
8	NORTHBOUND	19.2	2.9	48.9			0.0	2.9	19.2	16.3	49.3	2.9	18.9	0.0
	SOUTHBOUND	19.2	2.9	48.9			0.0	2.9	19.2	16.3	19.2	38.1	18.9	0.0
9	NORTHBOUND	52.3	25.4	38.3			0.0	25.4	52.3	26.9	62.0	15.6	18.9	0.0
	SOUTHBOUND	52.3	25.4	38.3			0.0	25.4	52.3	26.9	6.5	25.4	18.9	0.0
10	NORTHBOUND	61.2	26.1	30.2			0.0	26.1	61.2	35.1	7.3	26.1	18.9	0.0
	SOUTHBOUND	61.2	26.1	30.2			0.0	26.1	61.2	35.1	61.2	14.8	18.9	0.0

```
                                                          PHASE SETTINGS -- SECONDS

                          - - - - GREEN - - - -     - - - - LEFT  - - - -     - - - -  RED  - - - -     - - - - - - - -  BAND  - - - - - - -
SIGNAL                                                                                                                               ADVANCED BY
  NO.   DIRECTION        BEGIN    END  DURATION     BEGIN    END  DURATION    BEGIN    END  DURATION    BEGIN    END  DURATION   QUEUE CLEAR
                                                                                                                                     TIME

  11   NORTHBOUND        25.4     2.6    42.4       54.8     2.6    13.0       2.6    25.4    22.8       39.8    58.7    18.9          0.0
       SOUTHBOUND        25.4    54.8    29.4                        0.0      54.8    25.4    35.9       25.4    44.3    18.9          0.0


                                                         PROGRESSION TIMES AND SPEEDS

                                              NORTHBOUND                                              SOUTHBOUND

                                         PROGRESSION       PROGRESSION                          PROGRESSION       PROGRESSION
      SIGNAL                  LENGTH    TRAVERSAL TIME        SPEED              LENGTH        TRAVERSAL TIME        SPEED
        NO.                   (FEET)        (SECS)        (MILES/HOUR)           (FEET)            (SECS)        (MILES/HOUR)

         1
              --------       810.000        25.103           22.000             810.000           28.172           19.604
         2
              --------       1105.00        37.670           20.000             1105.00           41.856           18.000
         3
              --------       755.000        23.399           22.000             755.000           28.513           18.054
         4
              --------       800.000        27.273           20.000             800.000           30.303           18.000
         5
              --------       360.000        13.141           18.679             360.000           13.572           18.085
         6
              --------       230.000        8.5537           18.333             230.000           7.9585           19.705
         7
              --------       830.000        28.295           20.000             830.000           26.147           21.643
         8
              --------       410.000        12.707           22.000             410.000           12.707           22.000
         9
              --------       340.000        10.537           22.000             340.000           10.537           22.000
        10
              --------       1050.00        32.541           22.000             1050.00           35.796           20.000
        11

    ENTIRE ARTERY            6690.00        219.22           20.807             6690.00           235.56           19.364
```

```
**** MAXBAND END ****
```

```
                     **** MAXBAND MAXIMAL BANDWIDTH TRAFFIC SIGNAL SETTING OPTIMIZATION PROGRAM ****

                                                 **** MAXBAND INPUT CARDS ****

COMM    COMMENT CARDS MAY BE PLACED ANYWHERE
START         0    0
MPCODE         10000  100 1000  100    0
COMM                         IN THE DECK.
SETUP              6                   0              W         SAMPLE
ARTERY       30  120                        1    6
ART2         -1   -1   -1   35    3    3   35    3    3
MAP                1    1                                       STREET 1
VOLUME           506  135  436  205 1280    0  821  122
CAPACITY        3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN       .1000.0500          .1000.0500
COMM
COMM    ON MAIN STREET, MINIMUM THROUGH SPLIT IS .1000 CYCLES, AND MINIMUM
COMM     LEFT SPLIT IS .0500 CYCLES, IN BOTH DIRECTIONS.
COMM    MINIMUM CROSS STREET CORE TIME IS .1000 + .0500 = .1500 CYCLES.
COMM
LENGTH
LEFTPAT       1    1    1    1
MAP                2    2                                       STREET 2
VOLUME           656   49  501  204 1471  220  912   38
CAPACITY        3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN       .1000.0500          .1000.0500
LENGTH                              3375
LEFTPAT       1    1    1    1
QUEUE                              .0500     .0500
COMM    GIVING BANDWIDTH ADVANCE TIMES.
MAP                3    3                                       STREET 3
VOLUME           849   17  788   78 1496   62  944   19
CAPACITY        3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN       .1000.0500          .1000.0500
LENGTH                              1150
LEFTPAT       1    1    1    1
MAP                4    4                                       STREET 4
VOLUME           584   95  645   34 1512   31  914   90
CAPACITY        3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN       .1000.0500          .1000.0500
LENGTH                               575
LEFTPAT       1    1    1    1
SPEED                                 32    2   32    2
COMM    OVERRIDING ARTERY WIDE DESIGN SPEEDS AND TOLERANCES.
MAP                5    5                                       STREET 5
VOLUME           637   95  586  146 1600  158  950   94
CAPACITY        3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN       .1000.0500          .1000.0500
LENGTH                              2500
LEFTPAT       1    1    1    1
QUEUE                              .0500     .0500
COMM    GIVING BANDWIDTH ADVANCE TIMES.
SPEED                                        4         2
COMM    OVERRIDING ARTERY WIDE SPEED TOLERANCES.
MAP                6    6                                       STREET 6
VOLUME           647   97  603  141 1499  148  850    0
CAPACITY        3000 1500 3000 1500 3000 1500 3000 1500
MINGREEN       .1000.0500          .1000.0500
LENGTH                              2350
LEFTPAT       1    1    1    1
END
```

```
DATA HAS BEEN SUCCESSFULLY ENTERED.
```

```
                                        **** MAXBAND INPUT DATA SUMMARY ****

                                                 MPCODE VALUES

MAXIMUM BRANCH AND BOUND ITERATIONS (MAXRBB):      10000     MAXIMUM BRANCH AND BOUND REINVERSIONS (MAXIBB):    100
MAXIMUM LINEAR PROGRAM ITERATIONS (MAXITR):  1000    MAXIMUM LINEAR PROGRAM REINVERSIONS (MAXINV):   100
RESTART: 0     (0 -- JOB IS NOT A RESTART; 1 -- JOB IS A RESTART)


THIS IS AN ARTERY PROBLEM.

NAME OF ARTERY: SAMPLE                 NUMBER OF INTERSECTIONS:  6
LOWER CYCLE LIMIT:  30.00      SECS     UPPER CYCLE LIMIT:  120.0      SECS

ARTERY IS ENTERED FROM:  WEST      UNITS: ENGLISH
                                                                          SOURCE *
TARGET BANDWIDTH RATIO  WESTBOUND TO  EASTBOUND (K):            .60B6             1
WEIGHT OF  EASTBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(1)):  1.243             1
WEIGHT OF  WESTBOUND BANDWIDTH IN OBJECTIVE FUNCTION (C(2)):  .7567             1
                                                 * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)


                                                 ARTERY WIDE VALUES
                                                          EASTBOUND           WESTBOUND

                  DESIGN SPEED (MILES/HOUR):                       35.00               35.00
                  TOLERANCES (MILES/HOUR):                         3.000               3.000
                  CHANGES BETWEEN LINKS (MILES/HOUR):              3.000               3.000


                                                 INTERSECTION VALUES
                                                        EASTBOUND                                    WESTBOUND
                          LEFT                        SPLITS   - - - - SPLITS - - - -     QUEUE      - - - - SPLITS - - - -     QUEUE
SIGNAL  NODE  SEQ.  CHOICES     CROSS STREET    SOURCE    GREEN    LEFT      RED     CLEARANCE    GREEN    LEFT      RED     CLEARANCE
  NO.    NO.   NO.   1234 +         NAME            *      - - - (FRACTIONS OF A CYCLE) - - -      - - - (FRACTIONS OF A CYCLE) - - -

  1       1     1    1111    STREET 1            1     0.5246   0.0500   0.4754   0.0         0.6246   0.1500   0.3754   0.0

  2       2     2    1111    STREET 2            1     0.5634   0.2137   0.4366   0.0500      0.3997   0.0500   0.6003   0.0500

  3       3     3    1111    STREET 3            1     0.5B92   0.1052   0.4108   0.0         0.5340   0.0500   0.4660   0.0

  4       4     4    1111    STREET 4            1     0.5983   0.0500   0.4017   0.0         0.6270   0.0787   0.3730   0.0

  5       5     5    1111    STREET 5            1     0.5BB9   0.1643   0.4111   0.0500      0.4938   0.0692   0.5062   0.0500

  6       6     6    1111    STREET 6            1     0.6174   0.2095   0.3B26   0.0         0.4579   0.0500   0.5421   0.0

                    * (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

       NOTE:  THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

                                  + (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

                        PATTERN 1 --  EASTBOUND LEFT LEADS GREEN;  WESTBOUND LEFT  LAGS GREEN
                        PATTERN 2 --  EASTBOUND LEFT  LAGS GREEN;  WESTBOUND LEFT LEADS GREEN
                        PATTERN 3 --  EASTBOUND LEFT LEADS GREEN;  WESTBOUND LEFT LEADS GREEN
                        PATTERN 4 --  EASTBOUND LEFT  LAGS GREEN;  WESTBOUND LEFT  LAGS GREEN
                        MINIMUM GREEN TIMES FACING APPROACHES -- FRACTIONS OF A CYCLE

SIGNAL        NORTHBOUND              SOUTHBOUND              EASTBOUND               WESTBOUND
  NO.     THROUGH     LEFT        THROUGH     LEFT        THROUGH     LEFT        THROUGH     LEFT

  1        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500

  2        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500

  3        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500

  4        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500

  5        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500

  6        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500        0.1000    0.0500

                                              LINK VALUES
                                  EASTBOUND                                       WESTBOUND

 SIGNAL                LENGTH       SPEED       TOLERANCE       LENGTH       SPEED       TOLERANCE
  NO.                  (FEET)   (MILES/HOUR)  (MILES/HOUR)      (FEET)   (MILES/HOUR)  (MILES/HOUR)

  1
        --------      3375.00      35.000        3.0000        3375.00      35.000        3.0000
  2
        --------      1150.00      35.000        3.0000        1150.00      35.000        3.0000
  3
        --------      575.000      32.000        2.0000        575.000      35.000        3.0000
  4
        --------      2500.00      35.000        4.0000        2500.00      32.000        2.0000
  5
        --------      2350.00      35.000        3.0000        2350.00      35.000        2.0000
  6

                                VOLUMES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL        NORTHBOUND              SOUTHBOUND              EASTBOUND               WESTBOUND
  NO.     THROUGH     LEFT        THROUGH     LEFT        THROUGH     LEFT        THROUGH     LEFT

  1        506.00    135.00        436.00    205.00        1280.0    .0            821.00    122.00

  2        656.00    49.000        501.00    204.00        1471.0    220.00        912.00    38.000

  3        849.00    17.000        788.00    78.000        1496.0    62.000        944.00    19.000

  4        584.00    95.000        645.00    34.000        1512.0    31.000        914.00    90.000

  5        637.00    95.000        586.00    146.00        1600.0    158.00        950.00    94.000

  6        647.00    97.000        603.00    141.00        1499.0    148.00        850.00    .0
```

```
                                   CAPACITIES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL          NORTHBOUND            SOUTHBOUND             EASTBOUND             WESTBOUND
 NO.         THROUGH    LEFT       THROUGH    LEFT       THROUGH    LEFT       THROUGH    LEFT

  1          3000.0    1500.0      3000.0    1500.0      3000.0    1500.0      3000.0    1500.0

  2          3000.0    1500.0      3000.0    1500.0      3000.0    1500.0      3000.0    1500.0

  3          3000.0    1500.0      3000.0    1500.0      3000.0    1500.0      3000.0    1500.0

  4          3000.0    1500.0      3000.0    1500.0      3000.0    1500.0      3000.0  . 1500.0

  5          3000.0    1500.0      3000.0    1500.0      3000.0    1500.0      3000.0    1500.0

  6          3000.0    1500.0      3000.0    1500.0      3000.0    1500.0      3000.0    1500.0
```

```
MPCODE HAS SUCCESSFULLY COMPLETED.
 A REPORT BASED ON THE OPTIMAL SOLUTION WILL BE WRITTEN.

                                              **** MPCODE STATISTICS ****

   NUMBER OF BRANCH AND BOUND ITERATIONS PERFORMED:        607     NUMBER OF BRANCH AND BOUND REINVERSIONS PERFORMED:

   MAXIMUM NUMBER OF ITERATIONS PERFORMED BY A LINEAR PROGRAM:    37
   MAXIMUM NUMBER OF REINVERSIONS PERFORMED BY A LINEAR PROGRAM:    0

   NUMBER OF SOLUTIONS FOUND:   7     VALUE OF OBJECTIVE FUNCTION AT LAST SOLUTION:  .954653
```

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                              **** MAXBAND SOLUTION REPORT ****

THIS IS AN ARTERY PROBLEM.

NAME OF ARTERY: SAMPLE              NUMBER OF INTERSECTIONS:  6
ARTERY IS ENTERED FROM:  WEST     UNITS: ENGLISH

                                      **** BEST SOLUTION ****

CYCLE TIME:  59.57     SECS      EASTBOUND BANDWIDTH (B(1)): 0.5246      WESTBOUND BANDWIDTH (B(2)): 0.3997
                                          (FRACTION OF A CYCLE)                        (FRACTION OF A CYCLE)

OBJECTIVE FUNCTION (C(1)B(1) + C(2)B(2)):  .954653

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE  EASTBOUND DIRECTION AT SIGNAL 1.


                                         INTERSECTION INFORMATION

                        SIGNAL    NODE   SEQUENCE   CROSS STREET   LEFT TURN PATTERN
                         NO.      NO.      NO.          NAME           SELECTED

                          1        1        1      STREET 1               1

                          2        2        2      STREET 2               2

                          3        3        3      STREET 3               1

                          4        4        4      STREET 4               2

                          5        5        5      STREET 5               1

                          6        6        6      STREET 6               2
```

PHASE SETTINGS -- FRACTIONS OF A CYCLE

SIGNAL NO.	DIRECTION	GREEN			LEFT			RED			BAND			
		BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	.0	.5246	0.5246	.0	.0500	0.0500	.5246	.0	0.4754	.0	.5246	0.5246	0.0
	WESTBOUND	.0500	.6746	0.6246	.5246	.6746	0.1500	.6746	.0500	0.3754	.0500	.4497	0.3997	0.0
2	EASTBOUND	.9665	.5299	0.5634	.3162	.5299	0.2137	.5299	.9665	0.4366	.9665	.4911	0.5246	0.0500
	WESTBOUND	.9165	.3162	0.3997	.9165	.9665	0.0500	.3162	.9165	0.6003	.9165	.3162	0.3997	0.0500
3	EASTBOUND	.3285	.9177	0.5892	.3265	.4337	0.1052	.9177	.3285	0.4108	.3425	.8671	0.5246	0.0
	WESTBOUND	.4337	.9677	0.5340	.9177	.9677	0.0500	.9677	.4337	0.4660	.5680	.9677	0.3997	0.0
4	EASTBOUND	.4624	.0607	0.5983	.0107	.0607	0.0500	.0607	.4624	0.4017	.5361	.0607	0.5246	0.0
	WESTBOUND	.3837	.0107	0.6270	.3837	.4623	0.0787	.0107	.3837	0.3730	.3837	.7833	0.3997	0.0
5	EASTBOUND	.2837	.8726	0.5889	.2837	.4480	0.1643	.8726	.2837	0.4111	.3002	.8248	0.5246	0.0500
	WESTBOUND	.4480	.9418	0.4938	.8726	.9418	0.0692	.9418	.4480	0.5062	.5421	.9418	0.3997	0.0500
6	EASTBOUND	.9152	.5326	0.6174	.3231	.5326	0.2095	.5326	.9152	0.3826	.0080	.5326	0.5246	0.0
	WESTBOUND	.8652	.3231	0.4579	.8652	.9152	0.0500	.3231	.8652	0.5421	.8652	.2649	0.3997	0.0

PHASE SETTINGS -- SECONDS

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	BAND ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	0.0	31.3	31.3	0.0	3.0	3.0	31.3	0.0	28.3	0.0	31.3	31.3	0.0
	WESTBOUND	3.0	40.2	37.2	31.3	40.2	8.9	40.2	3.0	22.4	3.0	26.8	23.8	0.0
2	EASTBOUND	57.6	31.6	33.6	18.8	31.6	12.7	31.6	57.6	26.0	57.6	29.3	31.3	3.0
	WESTBOUND	54.6	18.8	23.8	54.6	57.6	3.0	18.8	54.6	35.6	54.6	18.8	23.8	3.0
3	EASTBOUND	19.6	54.7	35.1	19.6	25.8	6.3	54.7	19.6	24.5	20.4	51.7	31.3	0.0
	WESTBOUND	25.8	57.6	31.8	54.7	57.6	3.0	57.6	25.8	27.8	33.8	57.6	23.8	0.0
4	EASTBOUND	27.5	3.6	35.6	0.6	3.6	3.0	3.6	27.5	23.9	31.9	3.6	31.3	0.0
	WESTBOUND	22.9	0.6	37.4	22.9	27.5	4.7	0.6	22.9	22.2	22.9	46.7	23.8	0.0
5	EASTBOUND	16.9	52.0	35.1	16.9	26.7	9.8	52.0	16.9	24.5	17.9	49.1	31.3	3.0
	WESTBOUND	26.7	56.1	29.4	52.0	56.1	4.1	56.1	26.7	30.2	32.3	56.1	23.8	3.0
6	EASTBOUND	54.5	31.7	36.8	19.2	31.7	12.5	31.7	54.5	22.8	0.5	31.7	31.3	0.0
	WESTBOUND	51.5	19.2	27.3	51.5	54.5	3.0	19.2	51.5	32.3	51.5	15.8	23.8	0.0

```
                              PROGRESSION TIMES AND SPEEDS

                             EASTBOUND                                        WESTBOUND

                             PROGRESSION     PROGRESSION                      PROGRESSION     PROGRESSION
 SIGNAL            LENGTH  TRAVERSAL TIME       SPEED           LENGTH     TRAVERSAL TIME       SPEED
  NO.              (FEET)      (SECS)       (MILES/HOUR)        (FEET)         (SECS)       (MILES/HOUR)

   1
       --------   3375.00      60.556          38.000          3375.00         67.526          34.078
   2
       --------   1150.00      22.403          35.000          1150.00         23.737          33.032
   3
       --------   575.000      11.531          34.000          575.000         10.984          35.691
   4
       --------   2500.00      48.499          35.146          2500.00         50.134          34.000
   5
       --------   2350.00      42.165          38.000          2350.00         43.305          37.000
   6

ENTIRE ARTERY     9950.00      185.15          36.640          9950.00         195.69          34.668
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**** MAXBAND END ****
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REFERENCES

Little, John D.C., "The Synchronization of Traffic Signals by Mixed-Integer Linear Programming", Operations Research, Vol. 14, No. 4, July-August, 1966, pp. 568-594

Little, John D.C., Maximal Bandwidth for Arterial Traffic Signals: Theory and Interactive Computation, Massachusetts Institute of Technology, Alfred P. Sloan School of Management, Working Paper WP 970-78, September 1977

Land, A. and Powell, S., Fortran Codes for Mathematical Programming, London: John Wiley and Sons, 1973

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. **Improved Highway Design and Operation for Safety**

   Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. **Reduction of Traffic Congestion, and Improved Operational Efficiency**

   Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. **Environmental Considerations in Highway Design, Location, Construction, and Operation**

   Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. **Improved Materials Utilization and Durability**

   Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. **Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety**

   Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. **Improved Technology for Highway Construction**

   This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. **Improved Technology for Highway Maintenance**

   This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. **Other New Studies**

   This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

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* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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